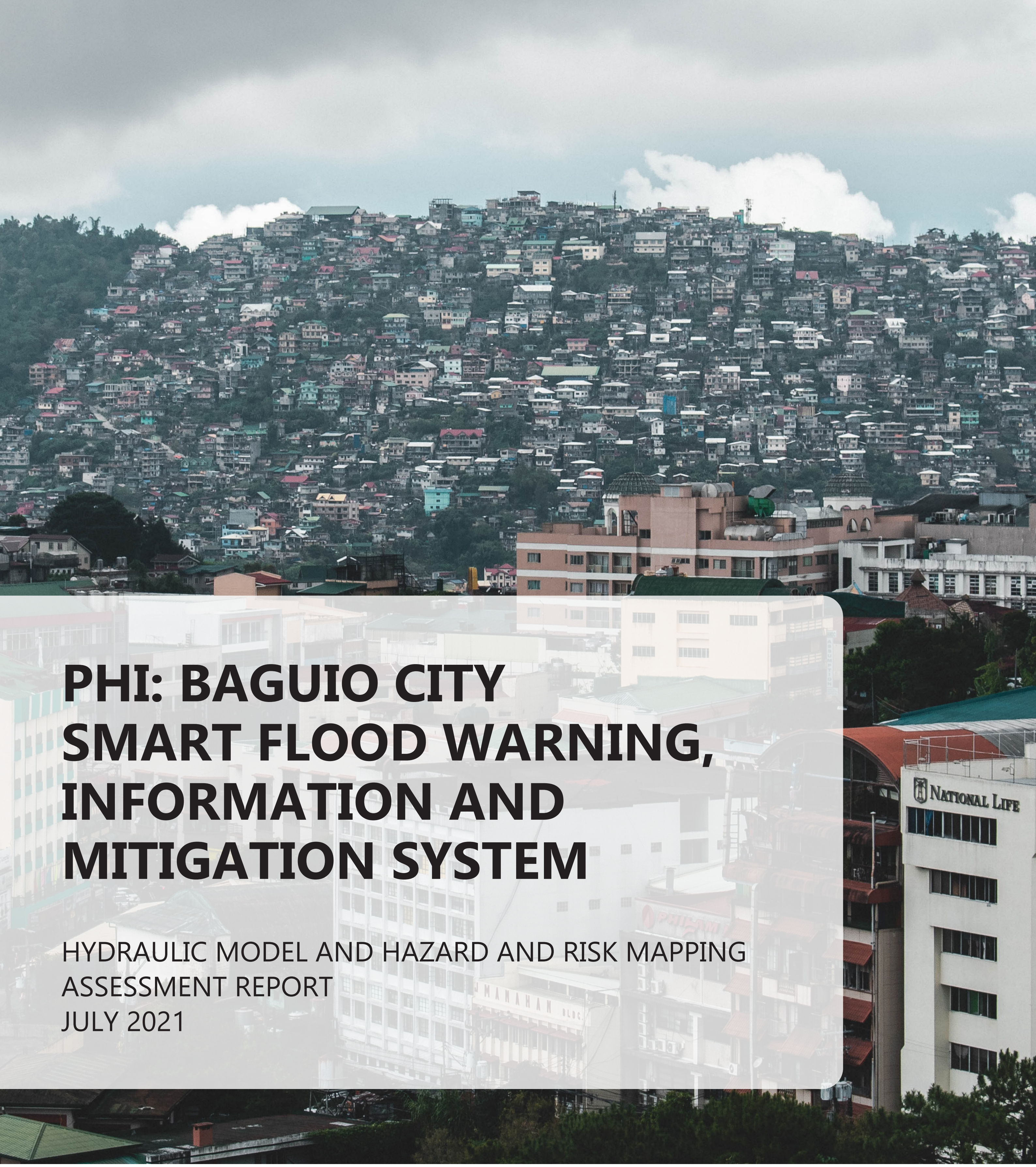

PHI: BAGUIO CITY SMART FLOOD WARNING, INFORMATION AND MITIGATION SYSTEM

HYDRAULIC MODEL AND HAZARD AND RISK MAPPING ASSESSMENT REPORT

JULY 2021

ASEAN AUSTRALIA SMART CITIES TRUST FUND
Asian Development Bank

Australian Government
Department of Foreign Affairs and Trade

ADB


Source: Asian Development Bank

RAMBOLL

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Description	**This Hydraulic Model and Risk Assessment Report is the second deliverable in the project "PHI: Baguio City Smart Flood Warning, Information and Mitigation System"**
Cover image	**Asian Development Bank**

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ABBREVIATIONS

AASCTF	Australia ASEAN Smart Cities Trust Fund
ADB	Asian Development Bank
AR	Assessment Report (from the IPCC)
CADSS	City Adaptation Decision Support System
CDRA	Climate and Disaster Risk Assessment
CDRRMO	City Disaster Risk Reduction and Management Office
CDS	Chicago Design Storm
CEO	City Engineering Office
CERAM	Climate Extremes Risk Analysis Matrix
CLIRAM	Climate Information Risk Analysis Matrix
CLUP	Comprehensive Land Use Plan 2013-2023
DEM	Digital Elevation Model
DFAT	Department of Foreign Affairs and Trade, Australia
DHSUD	Department of Human Settlements and Urban Development
DPWH	Department of Public Works and Highways
DOST	Department of Science and Technology
ENSO	El Niño-Southern Oscillation
FEWS	Flood Early Warning System

FME	Feature Manipulation Engine
GESI	Gender Equality and Social Inclusion
ICHARM	International Centre for Water Hazard and Risk Management
IDF	Intensity-Duration-Frequency
IFSAR	Interferometric Synthetic Aperture Radar
IPCC	Intergovernmental Panel on Climate Change
LGU	Local Government Unit
LIDAR	Light Detection and Ranging
M&E	Monitoring & Evaluation
NAMRIA	National Mapping and Resource Information Authority
NbS	Nature-based Solutions
NOAA	National Oceanic and Atmospheric Administration
RA	Risk Assessment
OSM	OpenStreetMap
PAGASA	Philippine Atmospheric Geophysical and Astronomical Services Administration
UNESCO	United Nations Educational, Scientific and Cultural Organization
UNFCCC	United Nations Framework Convention on Climate Change

EXECUTIVE SUMMARY

In April 2019, the Asian Development Bank (ADB) approved the establishment of the ASEAN Australia Smart Cities Trust Fund (AASCTF or the Fund) under the Urban Financing Partnership Facility, with financing provided by the Government of Australia, through its Department of Foreign Affairs and Trade (DFAT). Through this mechanism, the ADB is supporting Baguio City in implementing the Smart Flood Early Warning, Information and Mitigation System project, which will include four outputs: (i) smart flood early warning information system (FEWS) established and operational; (ii) real-time data capture system established in four river basins in Baguio City; (iii) flood mitigation action plan prepared; and (iv) city twinning programme for smart flood warning and mitigation implemented.

The occurrence of flooding and landslides, both regular phenomena in Baguio City, threatens Baguio's sustained and long-term economic development, supported by a dynamic tourism sector with Baguio considered the "summer capital of the Philippines". By having a high vulnerability to climate hazards, combined with the expansion of impervious paved areas, Baguio is experiencing increasing runoff volumes and flood damages.

This Hydraulic Model and Hazard and Risk Assessment report (Task 2) contributes to the overall understanding of the flooding dynamics in Baguio, driven significantly by its hilly topography, the rivers draining the city, the urban footprint and the urban drainage system, which did not form part of the hydraulic modelling in this study as there is a critical lack of data.

Through a statistical analysis of observed extreme rainfall values and an estimation of extreme rainfall events for future conditions, the study recommends applying a 'safety' factor to rainfall design intensities of 25% to estimate future rainfall. The safety factor considers the present and future uncertainty of design rainfall events, independent of return periods, and has been used in the hydraulic modelling undertaken in this report when simulating future climate change scenarios.

The 1D/2D hydrodynamic modelling, supported by the measurement of more than 60 river cross-sections, shows that the Balili catchment is the most flood prone area in Baguio, with 10 Barangays identified as experiencing recurrent flooding, incl. Rock Quarry, Lower and the area near Wright Park. The affected infrastructure includes roads, buildings, and public parks. Despite uncertainties in the modelling, the results were largely qualitatively validated by the LGUand by comparison to historical disaster data from the City Disaster Risk Reduction and Management Office (CDRRMO).

The landslide assessment confirmed the findings of previous landslide susceptibility mapping projects, highlighting that the flood modelling carried out in this study supports the current knowledge in Baguio whereby landslides are initiated in sloped areas due to rainfall and subsequent water saturation and destabilization of topsoils.

Using data from the CDRA, the GIS-based flood risk assessment maps the area around the city centre, and the northern and eastern parts of the city as being at most risk, for current and future conditions. In overall terms, more than 60% of the city is at risk of current or future flooding.

The results of this study can be used to inform decisions related to flood protection investments, land use changes and stormwater infrastructure, among other topics. Moreover, the results can also improve coordination across city agencies through the development of integrated flood management strategies at Barangay level.

A Hydraulic Model and Risk Mapping Virtual Workshop took place on 22 June 2021, with 40 people from different organizations. This report’s findings were presented and discussed in an interactive and participative setup during the workshop, which also allowed participants to learn about state-of-the-art modelling tools and risk assessment methods, providing inspiration as to how these tools can help increase resilience to climate risks through a holistic climate adaptation planning process.

1. INTRODUCTION

Figure 1: Vegetable farm, Philippines
Source: Asian Development Bank

1.1 PROGRAMME (AASCTF)

In April 2019, the Asian Development Bank (ADB) approved the establishment of the ASEAN Australia Smart Cities Trust Fund (AASCTF or the Fund) under the Urban Financing Partnership Facility, with financing provided by the Government of Australia, through its Department of Foreign Affairs and Trade (DFAT). The Fund's envisioned impact aligns with ADB's Strategy 2030, as well as ASEAN's Sustainable Urbanization Strategy which aims to promote high quality of life, competitive economies, and sustainable environments. The expected outcome of the Fund will be that through the adaptation and adoption of digital solutions, across three core functional areas (planning systems, service delivery and financial management), systems and governance in participating ASEAN cities are improved, in particular by way of:

- Strengthening city planning processes by enhancing the collection, storage, analysis and utilization of data on geospatial platforms.
- Promoting the use of integrated and smart network management systems to strengthen operational systems and to improve quality and efficiency of service delivery.
- Introducing integrated financial management information systems to improve institutional credit worthiness and fiscal standing.

The Fund acts as a mechanism for facilitating and channeling resources and financing for eligible projects, as well as activities agreed between DFAT and ADB for project preparation, implementation, and capacity development.

1.2 BACKGROUND AND PROJECT RATIONALE

The occurrence of flooding and landslides, both regular phenomena in Baguio City, threaten Baguio's sustained and long-term economic development. Baguio City is considered the "summer capital of the Philippines", attracting 1.8 million tourists in 2018, with an annual growth rate of ca. 16%. In 2009, Baguio was significantly impacted by Typhoons Ondoy and Pepeng, resulting in more than 3,000 people being affected by flooding, and almost 2,500 people being affected by landslides. Japanese researchers from National Research Institute for Earth Science and Disaster Prevention have concluded that the underlying causes behind the 2009 flooding were related to a limited drainage capacity due to obstructions caused by the accumulation of waste, and also by the presence of built-up structures (urban sprawl)[1]. In addition, the presence of illegal settlers in flood prone areas worsens Baguio's exposure and vulnerability towards flood disasters.

By being exposed and having a high vulnerability to climate hazards, combined with the expansion of impervious paved areas within the city and its surroundings, Baguio is experiencing increasing runoff volumes and flood damages. All these impacts are expected to be compounded by climate change, which will very likely cause an increase in the frequency and intensity of rainfall events and further exacerbate flooding events and rain-induced landslides.

1 T. Inokuchi, T. Nakasu and T. Sato, 2011, Landslide Disaster around Baguio City caused by Typhoon Pepeng in 2009, National Research Institute for Earth Science and Disaster Prevention, Japan.

The ADB, through the AASCTF, is supporting Baguio City in implementing the Smart Flood Early Warning, Information and Mitigation System project. The project will assist the city with both the planning for flood mitigation and the delivery of the services of flood early warning and responses, using smart technologies. The project outcome is improved flood early warning system, responses, and mitigation measures of Baguio City. It has four outputs: (i) smart flood early warning information system (FEWS) established and operational; (ii) real-time data capture system established in four river basins in Baguio City; (iii) flood mitigation action plan prepared; and (iv) city twinning programme for smart flood warning and mitigation implemented.

The FEWS will be developed with Baguio Local Government Unit (LGU) and other key stakeholders to improve community disaster preparedness, raise awareness, and ensure ownership. The FEWS is also set to become an integral element within the overall vision of Baguio City to become a truly resilient, dynamic, and smart city.

1.3 PROJECT OVERALL APPROACH

The overall approach followed in producing this project's four outputs (outlined in section 1.2) is to breakdown the project into working tasks (or stages), with each task/stage containing key activities, and where inter-dependencies between tasks/activities are accounted for by defining milestones and keeping close contact with the project's working group. The project tasks and associated key activities and deliverables are shown in the table below.

In relation to Task 2, which is the focus of this report, the following are important updates:

- The urban drainage model component has not been included in the modelling work covered under this report, as there is a significant lack of drainage data in Baguio which makes setting up a hydraulic model for the entire city an impossible task. To cope with this much important gap, and through consultation with the LGU and ADB, a decision was made to continue with the hydraulic modelling in Task 2 without including the urban drainage component. Instead, the urban drainage system in Baguio would be looked at in more detail on Task 5 (Flood Mitigation Action Plan), allowing in this way more time to better understand the system with the aim of at least mapping the primary drainage infrastructure.

- In continuation of the above, Ramboll has held three workshops with staff from the City Engineering Office (CEO) to discuss this matter and define a common way of tackling it. Ramboll is currently preparing a roadmap for Task 5 outlining the detailed tasks to follow, incl. actions regarding how to tackle the lack of data on the urban drainage system. Task 5's final report is expected to be ready in November 2021.

Table 1: Project tasks and associated activities and deliverables

Task	KEY ACTIVITIES AND DELIVERABLES
Task 1 – Baseline Assessment	• Setup working group, conduct scope consultations, revise workplan • Data and Information Collection • Establish baseline on climate change data and information • Plan the on-the-job training component • **D1: Baseline Assessment Report** (delivered in January 2021)
Task 2 – Hydraulic model setup, including hazard and risk mapping (this report)	• Collect additional data, if needed, incl. river surveys • Confirm boundary conditions and target design levels for the hydraulic model and for inclusion of potential nature-based solutions (NbS) • Develop hydrologic model for all 4 rivers • Develop hydraulic model for the primary drainage system, incl. calibration • Hazard and Risk Assessment • On-the-job (OTJ) training • Twinning activities • **D2: Hydraulic Model and Hazard and Risk Mapping Assessment Report** (this report)
Task 3 – Design of a Flood Early Warning System (FEWS)	• Planning the framework of the FEWS • Procuring and installing measurement devices in selected locations for pilot river • Development of the pilot river real-time data acquisition system • Design the data storage and management system • Overall forecast system framework (database) • Setting up of FEWS at the LGU, and start of the real-time online simulations, before the monsoon • On-the-job (OTJ) training • Twinning activities • **D3: Flood Early Warning System Report**
Task 4 – Data dissemination and outreach plan	• Design dissemination and outreach activities, including: Website/Dashboard, web applications – SMS alerts, mobile apps, e-mail chimps, etc. • Define dissemination roles and responsibilities among key stakeholders • Development and dissemination of FEWS O&M plan. Maintenance will be undertaken during the monsoon period • On-the-job (OTJ) training • Twinning activities • **D4: Data Dissemination and Outreach Plan**
Task 5 – Flood Mitigation Action Plan	• Outline NbS to address flood risks, including: (i) key enabling criteria for implementation; and (ii) conceptual plans • Conduct hydrodynamic simulations of selected NbS • Prepare an NbS action/implementation plan with options for mitigation measures for future investments, including cost-benefit analysis • On-the-job (OTJ) training • Twinning activities • **D5: Flood Mitigation Action Plan**
Task 6 – Replication of real-time data capture, and Monitoring & Evaluation	• Procuring and installing measurement devices in the remaining three rivers • Evaluation of the FEWS (post-monsoon period) • Finalize data assimilation and forecast modelling • System Performance Assessment • On-the-job (OTJ) training • Twinning activities
Task 7 – Project completion	• Wrapping up everything • **D6: Final Report**

1.4 TWINNING AND NETWORKING

The aim of the Networking and Twinning programme is regional capacity building, knowledge sharing and strengthening the cooperation across ASEAN and Australian cities.

The Networking programme launched in May 2021, where Ramboll facilitated a semi-online introduction workshop in the city of Baguio on the 27th of May. A broad representation of stakeholders from the city government, academia and local CBOs attended the workshop. The workshop consisted of a general introduction to the AASCTF, three learning modules focusing on Smart Cities and a presentation of the Networking and Twinning activities.

In June 2021 approximately 150 city officials and other stakeholders participated in an online survey focusing on needs, interests, digital challenges and smart city priorities. The next step in the Networking activities is to analyse the data from survey.

The Twinning activities was presented during the workshop in Baguio where a preliminary identification of potential Twinning topics was conducted.

In June 2021, the project staff supported the Baguio municipality in the process of nominating the Twinning Coordinator. During July and August, the topics for Twinning cooperation will be selected and potential mentor cities identified. The Twinning cooperation is expected to start in September.

Figure 2 shows an overview of the Twinning programme which is divided into the six phases; ASSSES, PLAN, START, IMPLEMENT, MONITOR and SHARE. The City of Baguio are currently in the first phase.

MONTH 1-2:
ASSESS

DS ASSESSMENT to identify needs, and smart city priorities of recipient entor cities to be invited to ASSESS s & priorities, and identify possible jencies in the city.

NT LETTER SIGNED

MONTH 3-4:
PLAN

With support from AASCTF, recipient and mentor cities develop a 12-month **TWINNING PLAN** with specific targets and milestones.

MONTH 4:
START

Presentation and discussion of work plan, timeline, and deliverales for the next 12 months during the **KICK-OFF WORKSHOP.**

TWINNING PLAN DEVELOPED

ONTH 5-16:
IPLEMENT

implemented with the support of will be planned to understand the ities and learn from solutions from nd on-line events will complement ASCTF will **MONITOR & EVALUATE** progress.

LAN IMPLEMENTED

MONTH 6-18:
MONITOR

Periodic **PROGRESS MEETINGS** to report on progress, give feedback, and agree on new targets/milestones; Midterm evaluation after 6-7 months; Final evaluation after 18 months.

TWINNING PLAN REPORT

MONTH 18 ONWARDS:
SHARE

Recipient and mentor cities participate in **KNOWLEDGE SHARING ACTIVITIES** to exchange experiences and lessons on their twinning activities.

Figure 2: The Twinning Journey

1.5 FOCUS ON GENDER EQUALITY AND SOCIAL INCLUSION

Under the AASCTF programme, overall frameworks to guide critical cross-cutting aspects of Monitoring & Evaluating (M&E) and Gender Equality and Social Inclusion (GESI) are incorporated into each task order. In this regard, an action plan for Baguio City covering these activities is currently being developed in consultation and agreement with ADB and Baguio City LGU. The action plan, once finalized, will guide the subsequent activities relating to M&E and GESI to be undertaken throughout the remaining project period. Furthermore, a new Task Order-05 “PHI: Gender Transformative Approach for Strengthened Development, Application, and Replication of the Baguio City Smart Flood Early Warning System” is also being implemented in Baguio.

The links between Task Order-02 “PHI: Baguio City Smart Flood Warning, Information and Mitigation System” (of which this report is part of), and Task Order-05 will be looked in detail when Task 4 (Data dissemination and outreach plan) is addressed, later in the project. Thus, while the gender/social dimension of the FEWS is not addressed explicitly in this Hydraulic Model and Hazard and Risk Assessment report, it is indeed acknowledged to be a crucial component which will be elaborated and addressed in subsequent project activities and outputs.

1.6 REPORT OBJECTIVES AND STRUCTURE

This Hydraulic Model and Hazard and Risk Assessment report is the second report out of six reports to be produced in this project. The primary intended audience comprises technical personnel from the LGU and ADB. Other intended audiences comprise policy-makers, city planning officials and the broad general audience with knowledge and/or interest in risk assessments, climate adaptation and city resilience.

While the first report (Baseline Assessment, dated January 2021) focused on mapping the baseline in Baguio in regards to climate hazards, data and information gaps and FEWS outline, this report goes deeper into very technical themes necessary to address in depth to be able to support the development of the two main technical components in the project: the FEWS and the flood mitigation action plan (Task 5).

This report aims at answering the following questions:

- What are the main drivers, mechanisms, characteristics and impacts of flooding and landslides in Baguio?
- Where are the most flood prone areas in Baguio for current and future conditions, and how do flood hazard maps support the understanding of city-wide flood risks?
- How is Baguio expected to be affected by climate change in relation to changes to rainfall patterns, and what does that mean in terms of risk assessment and adaptation solutions?
- How is flood risk understood and dealt with in Baguio, and where are the most at-risk areas in the city?
- How are twinning and networking arrangements supporting cooperation across ASEAN and Australian cities, and which role is Baguio playing in this regard?
- What is the status of the on-the-job (OTJ) training in Baguio, and what are the capacity building activities planned to take place in this project?

Section 1 in this report introduces the AASCTF programme, describes this project's rationale and overall approach as well as the main questions to be answered by this report, together with the twinning and networking arrangements and the links to the Gender Equality and Social Inclusion work taking place in Baguio under another task order. Section 2 summarizes the main gaps identified in the previous Baseline Assessment Report, together with the key actions taken to cover those gaps as well as the current status of the OTJ training in Baguio. Section 3 deals with the climate change assessment. Section 4 describes the overall hydrodynamic modelling approach together with the methodology and results of the flood modelling. Section 5 describes the landslide assessment and mapping. Section 6 deals with the detailed flood risk assessment, and section 7 outlines the main conclusions and recommendations of this report.

2. UPDATE OF BASELINE ASSESSMENT

Figure 3: Expanse of buildings on flat, and steadily encroaching on mountainside areas in La Trinidad, Benguet, Philippines
Source: Asian Development Bank

2.1 MAIN GAPS IDENTIFIED IN TASK 1 AND MITIGATING ACTIONS

Several gaps were identified through the development of the baseline assessment for Baguio. Many of the gaps were dealt with during the baseline assessment, but some gaps remained pending to be addressed. These gaps are summarized in the table below, together with the key actions taken as part of the development of Task 2.

Table 2: Main gaps identified in the baseline assessment and corresponding mitigating actions undertaken in this task

Topic	Gap	Action
Data (GIS and non-GIS)	• Key data missing to be collected, or pending further clarification (e.g., critical/social infrastructure; public transportation; land use, etc.)	• Ramboll has collected and analyzed available data from OSM and consulted with the LGU in regard to validity and quality. Data is reported in detail in the following sections.
Climate Change	• Climate factors (or design safety factors) • Analysis of uncertainty bounds • Unclear trend analysis	• Ramboll has discussed extensively with PAGASA regarding IDF information, climate factors and other key climate-related issues. More details are given in section 3 of this report.
Hydrology/ Hydraulics	• Location of river inlets and outlets • No available river cross-sections (bathymetry data) • Data request for an additional station, Mamat-ing Bridge in La-Union • Discharge data within the FEWS project area is missing. • No gauging stations have been identified on the River Ambalanga • Urban drainage data not collected yet	• Ramboll has undertaken a river survey in the pre-monsoon period of 2021, covering more than 60 locations, incl. six river gauging stations and all four rivers in Baguio. • Ramboll has also developed a scope of works for the installation of several extra water-level monitoring stations (procurement yet to be approved by ADB), where a station is located on the river Ambalanga so that data can be collected in that basin. • Data from the Mamat-ing Bridge has now been collected and assessed. • Ramboll is leading a process, in close consultation with the LGU, regarding the mapping of the primary drainage infrastructure in Baguio. This will be dealt with in detail as part of Task 5 (Flood Mitigation Action Plan)

2.2 PRELIMINARY GAP ANALYSIS OF DRAINAGE INFRASTRUCTURE

Building on the table above, a preliminary gap analysis of drainage infrastructure has been looked at in more detail. Key stakeholders from the City Engineering Office (CEO) and the LGU have been engaged as part of this process to inform the analysis and clarify doubts. Data has been collected from EGIS, LGU and DPWH.

The coverage and connectivity of the data is generally good along major roads and in the central areas of Bailli around Burnham Park. However, there are significant gaps in the data related to the primary drainage system, especially along the main roads in Baguio. Throughout the city, the data contains drainage structures that are disconnected from the drainage network. Local stakeholders have confirmed that these structures are connected to the primary network through either underground infrastructures or terrain-based streams and canals missing in the source data.

Comparing the data to images from Google street view shows that the data (location and size of above-ground structures) align with google observations. Spot checks on Google Street view identified terrain-based drainage structures (e.g. open canals and culverts) missing from the available drainage data.

- The preliminary screening of urban drainage infrastructure identified the following data gaps:
- Disconnected drainage structures
- Missing drainage infrastructures
- Areas with no information on drainage infrastructure
- No information on invert levels and slopes
- No information on dimension of outlets
- Limited information on location and size of manholes and inlets
- Some drainage structures have no information on dimensions
- Inconsistencies between datasets in location and dimension of structures
- Limited information on the condition of the drainage network

Knowledge on connectivity between drainage infrastructure is crucial to properly model the drainage network. Furthermore, knowledge on invert levels, location of inlets and manholes, as well as dimensions, are essential for capturing the magnitude of flows and design capacities in the model. In task/stage 5, closure of drainage data gaps and validation of data quality will be continued through engagement of local stakeholders and, if feasible and possible, local surveys will also be implemented. The complete gap analysis and mitigating actions will be reported under task/stage 5.

2.3 ON-THE-JOB TRAINING

As documented in the Task 1 Baseline Assessment Report, the on-the-job training (OTJ) is planned to follow the overall project's timeline in order to equip the LGU with skills and knowledge for operating and maintaining the FEWS system. This system will be installed at and operated from the LGU's premises, which will require specific skills in operating the hydrological and hydraulic models supporting the FEWS and operating the entire FEWS setup. The FEWS design is currently being looked at in detail in Task 3 Design of a Flood Early Warning System (FEWS).

As the overall project has experienced delays in several fronts, the key milestone of installing the FEWS at the LGU's premises has been delayed compared to the original timeline. This means that although initial meetings with the selected trainees have been held, the OTJ training has been hampered by the delays in the project and by the difficulties in building capacities exclusively through virtual interactions. To cope with this, Ramboll is currently discussing with ADB the possibility of following another approach to capacity building, which is expected to be defined during Q3 of 2021.

The trainees identified so far include:

1. King Guinid (CDRRMO)
2. Stephanie Trinidad (CDRRMO)
3. Chester Comicho (City Engineering Office)
4. Jhomer Samoranos (City Environment and Parks Management)

3. CLIMATE CHANGE ASSESSMENT

Figure 4: After Typhoon Ketsana (Ondoy), 26 September 2009
Source: Asian Development Bank

This section describes the historical increase in annual and extreme rainfall in Baguio, using a range of different types of data (see Appendix A). A statistical analysis of extreme rainfall values has been performed, as well as an assessment of climate variability, notably through the El-Niño Southern Oscillation (ENSO), and how this affects rainfall patterns in the Philippines and Baguio. The climate change assessment also introduces an estimation of extreme rainfall events for future conditions, also called “climate factors” in the context of rainfall design intensities that account for uncertainties in the future climate.

All technical details can be found in Appendix A. This section of this report deals primarily with the key findings, summarized below.

3.1 KEY FINDINGS

3.1.1 HISTORICAL DATA

The mean annual temperature in Baguio has increased by 0.1 C° per decade during 1951-2015, like in the rest of the Philippines. Likewise, there are indications of an increase in the annual precipitation depth, mainly driven by increases in rainfall depths during the summer monsoon period. Analysis of rainfall measured at the local station in the city of Baguio (station 328) does not confirm this pattern, probably because the analysed rainfall series have not been through PAGASA’s standard quality assurance procedures.

The scientific literature assessed[2,3] did not find a significant increase in extreme 1-day rainfall in Baguio or a relation between rainfall variability and the mean global temperature. A simple analysis of rainfall measured at the local station in the city of Baguio (station 328), supports this finding.

2 M. Villafuerte, J. Matsumoto, I. Akasaka, H. Takahashi, H. Kubota and T. Cinco, 2014, Long-term trends and variability of rainfall extremes in the Philippines, Atmospheric Research, 137 (1-13).

3 M. Villafuerte, J. Matsumoto and H. Kubota, 2015, Changes in extreme rainfall in the Philippines (1911-2010) linked to global mean temperature and ENSO, International Journal of Climatology, vol. 35, no. 8, pp. 2033-2044.

3.1.2 EXTREME VALUE ANALYSIS

Analyses have been carried out, as a part of this project, including extreme value analysis on annual maximum events measured at station 328 in Baguio in the period 1949 - 2010. A three parameter log-normal distribution is fitted to the observed events, from this design rainfall events are estimated, see Table 3, together with their uncertainty. With a 68% confidence-interval the uncertainty bounds correspond to 8-25%. Uncertainties increase with increasing return periods.

According to PAGASA, the average effect of having El-Niño conditions compared to La-Niña conditions, leads to approximately 700 mm additional rainfall in the summer season (June-September) in Baguio[4]. Scientific literature finds that El-Niño conditions, leads to an increase in the extreme rainfall intensities between 5 and 17%, depending on the return period[5].

Table 3: Estimated design intensities for Baguio (mm) using the log-normal distribution on annual rainfall maximum depths. For other durations and/or return periods see Appendix A.

	10 min	60 min	120 min	1 day
3-year	29.14	78.31	120.50	424.45
10-year	52.84	138.49	214.14	670.16
20-year	71.58	184.57	281.32	814.62
100-year	133.73	332.55	483.79	1175.12

4 PAGASA, 2019, Local Stakeholders Workshop on Barriers and Opportunities on the access and utilization of weather and climate information. Action Ready Climate Knowledge to Improve Disaster Risk Management for Smallholder Farmers in the Philippines, Powerpoint presentation 23 July 2019. Shared by PAGASA 13 January 2021.

5 M. Villafuerte, J. Matsumoto and H. Kubota, 2015, Changes in extreme rainfall in the Philippines (1911-2010) linked to global mean temperature and ENSO, International Journal of Climatology, vol. 35, no. 8, pp. 2033-2044.

3.1.3 THE INFLUENCE OF ENSO

While El-Niño Southern Oscillation (ENSO) affects the rainfall patterns in the Philippines, its influence varies over the country. While most of the country will experience increased flood risk during La-Niña, the opposite is the case in the western, upper most part of the country, i.e. in the climate zone defined by the Cordillera Central mountain range.

According to PAGASA, the average effect of having El-Niño conditions compared to La-Niña conditions, leads to approximately 700 mm additional rainfall in the summer season (June-September) in Baguio[6]. Scientific literature finds that El-Niño conditions, leads to an increase in the extreme rainfall intensities between 5 and 17%, depending on the return period[7].

3.1.4 RAINFALL AND CLIMATE CHANGE

Climate model simulations for the province of Benguet does not point unequivocally towards a future increase in the rainfall depth during the summer monsoon period. The median projection across different emission scenarios and different climate models is a decrease of 10% in 2036-2056, with a span in the projections between 25% decrease and 25% increase. For the annual maximum daily rainfall depth, the median projection across both different emission scenarios and different climate models is an increase, but of less than 10%.

6 PAGASA, 2019, Local Stakeholders Workshop on Barriers and Opportunities on the access and utilization of weather and climate information. Action Ready Climate Knowledge to Improve Disaster Risk Management for Smallholder Farmers in the Philippines, Powerpoint presentation 23 July 2019. Shared by PAGASA 13 January 2021.

7 M. Villafuerte, J. Matsumoto and H. Kubota, 2015, Changes in extreme rainfall in the Philippines (1911-2010) linked to global mean temperature and ENSO, International Journal of Climatology, vol. 35, no. 8, pp. 2033-2044.

Large scale climate variability (like ENSO) has an influence on rainfall in Baguio and therefore it is important to consider when building robust flood adaptation measures. Presently there are no clear indications from climate model simulations on what explicit influence climate change will have on the extreme rainfall intensities. However, it seems indisputable that climate change will affect large scale circulations patterns one way or the other, perhaps as intensified El-Niño events[8].

Considering; the general uncertainty on the present-day intensities found from analysis of historical rainfall observation; the effect of ENSO; the projected future change in summer rainfall and in the annual maximum daily rainfall depth, Ramboll recommends applying a climate/safety factor, see Figure 5. The climate/safety factor considers the present and future uncertainty on the design rainfall and is added to design intensities from Table 3. Our recommendation is 25%. Design intensities representing the future is given in Table 4.

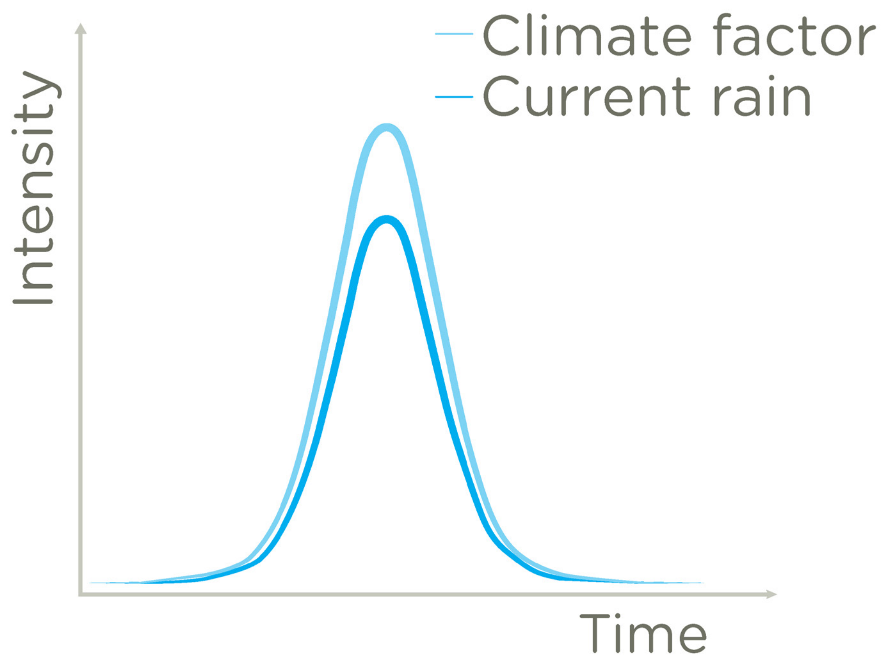


Figure 5: Conceptual visualization of the impact a climate factor on rainfall. A climate factor of 1.0 indicates no change in future rainfall and a climate factor of 1.25 indicates 25 % increase in future rainfall, and a climate factor of 1.5 indicates 50% increase in future rainfall.

8 Y. Ham, 2018, El Niño events will intensify under global warming, Nature - news and view [Online]. Available: https://www.nature.com/articles/d41586-018-07638-w.. [Accessed 5 2021].

Table 4: Estimated design intensities for Baguio (mm) representing a future climate using a climate /safety factor of 25%.

	10 min	60 min	120 min	1 day
3-year	36.43	97.89	150.63	530.56
10-year	66.05	173.11	267.68	837.70
20-year	89.48	230.71	351.65	1018.28
100-year	167.16	415.69	604.74	1468.90

The daily rainfall depth is given in Table 5, with and without the climate/safety factor. The depth is compared to the average rainfall depth of August in the city of Baguio, which is 900 mm looking at the climatological normal values. The table shows that the 10-year event in the future potentially will bring a rainfall depth that corresponds to the amount normally accumulated during an entire month.

Table 5: Rainfall depth for Baguio for the present day and a future under climate change

	Present day [mm]	% of monthly rain in August	Future [mm]	% of monthly rain in August
3-year event	425	47	531	59
10-year event	670	74	838	93
100-year event	1,175	131	1,469	163

3.1.5 RECOMMENDATION

Ramboll's overall recommendation based on the findings of the climate change assessment, is to apply a safety/climate factor to rainfall design intensities in Baguio. The safety factor considers the present and future uncertainty on the design rainfall. Ramboll recommends adding 25% to all design events independent of the return period. Presently, there is not enough evidence in the literature to justify the use of the safety factor that varies with return period.

In the development of hydraulic modelling results values from Table 3 are applied as the best estimate of the present day conditions, while values from Table 4 (including the factor of 25%) are applied considering future scenarios affected by climate change.

4. HYDROLOGICAL AND HYDRODYNAMIC MODELLING

Figure 6: Aerial photo show the damage caused by Typhoon Ulysses
Source: Asian Development Bank

This section describes the key aspects in the development of the entire hydrological and hydrodynamic modelling framework for the project, and more specifically on the approach followed in this report to develop the flood hazard maps, which inform the overall risk assessment in Baguio. All technical details can be found in the Appendix B. This section of this report deals primarily with the key assumptions, constraints, and findings.

4.1 WHY MODELLING?

This section describes the key aspects in the development of the entire modelling framework for the project, and more specifically on the approach followed in this report to develop the flood hazard maps, which inform the overall risk assessment in Baguio. All technical details can be found in the Appendix B. This section of this report deals primarily with the key assumptions, constraints, and findings.

4.2 MODELLING FRAMEWORK

The modelling framework followed in this project is presented in Figure 7. A combination of hydrodynamic 1D and 2D models are created and used throughout the different stages of the project, both to simulate scenarios for the Flood Mitigation Action Plan and to forecast flooding events for the FEWS. The purpose of the hydrodynamic flood modelling undertaken in Stage 2 (subject of this report) is to identify flood prone areas and map flood hazards in Baguio.

4.3 HYDROLOGICAL REGIME IN BAGUIO

Baguio City is drained by 4 major rivers, Balili flowing northwards, Bued flowing southwards, Galiano to the west and Ambalanga to the east. Out of the four rivers, Balili, Bued and Galiano drain most of the city, while Ambalanga drains very sparsely populated areas near the eastern boundary of the city. The four river catchments of Baguio City are characterized as mountainous with steep slopes leading runoff to the major rivers. Figure 8 presents an overview of the hydrology of Baguio City.

4.4 MODELLING APPROACH

The modelling approach is primarily based on capturing surface flows, as represented in the Digital Elevation Model (DEM), which was documented in the Baseline Assessment Report. While this approach disregards existing underground drainage infrastructure, it is sufficient to map areas that are particularly exposed to flooding, assuming that the drainage infrastructure is blocked. The key drainage path for the more densely built up areas of Baguio is identified as Balili river, hence this is modelled separately in a one-dimensional river flow model based on surveyed cross-sections.

To capture the flooding scenarios in Baguio City, a combination of dynamic 1D and 2D models are prepared with different levels of detail and spatial extents, both to simulate scenarios for the flood risk assessment, and as the foundation for further development in the following stages of the project.

The full modelling scheme consists of 4 independent model domains, delineated along the four river catchments for the Balili, Bued, Galiano and Ambalanga rivers. The models developed for each of the river basins are shown in Table 6.

Due to the gaps outlined in section 2.2 related to drainage infrastructure data, the approach is exclusively based on surface flow modelling, hence underground drainage network structures are not included in the flood modelling for risk mapping in Baguio. Natural streams are an integral part of the drainage system within Baguio; thus, 2D surface models are sufficient to capture major conveyance paths in Baguio and identify flood prone areas.

Appendix B includes all the details related to the model domains, setup of the models, boundary conditions, parameters, etc. The models are setup using the MIKE software suite, a state-of-the-art hydrodynamic modelling tool by DHI.

Table 6: Overview of models developed. The area [km2] indicates the area of the surface model domain.

River basin	Model Setup	Area [km2]
Balili	1D-2D coupled flood model	31
Ambalanga	2D Flood Model	13
Bued	2D Flood model	38
Galeano	2D Flood model	50

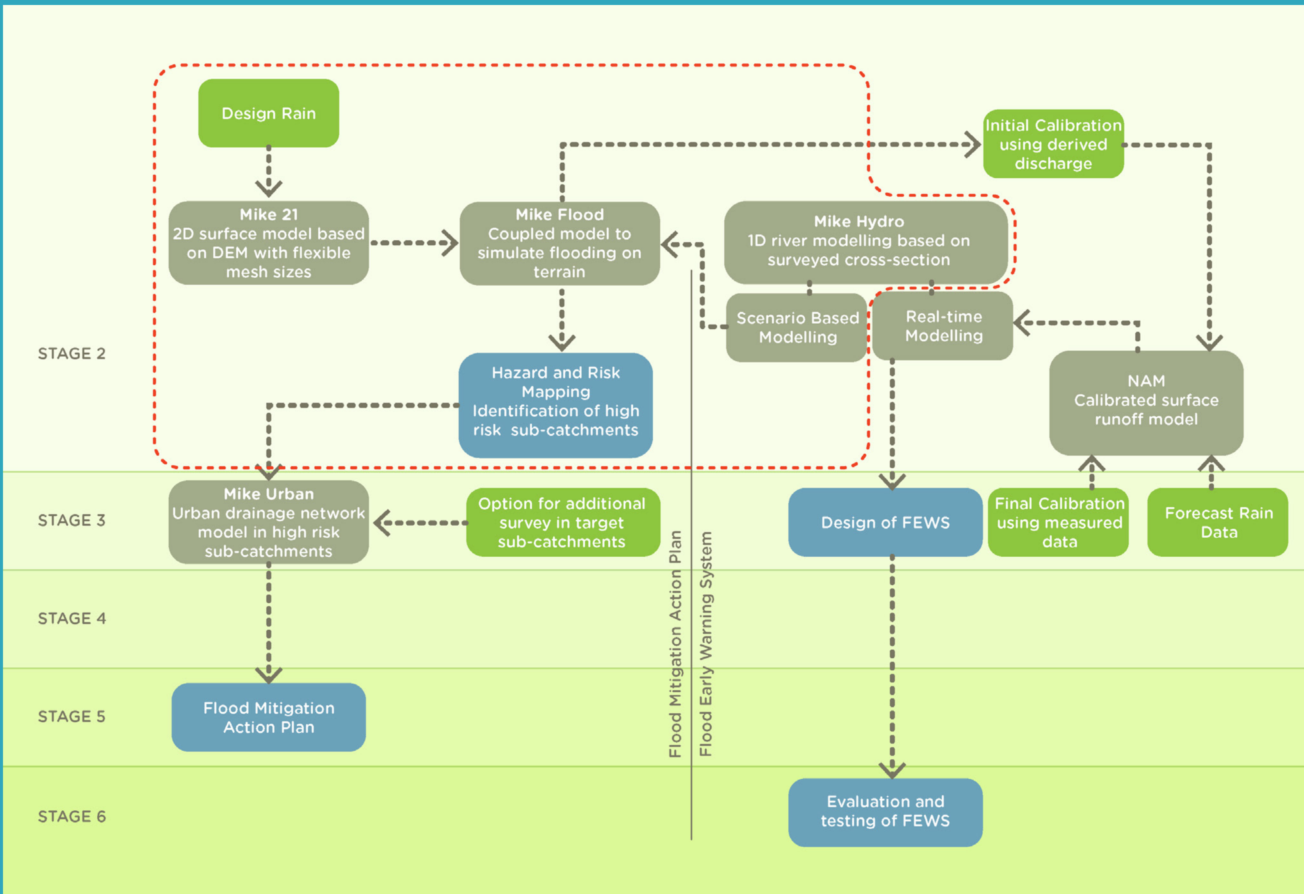


Figure 7: Modelling framework for the entire project. This report focuses on Stage 2, and more specifically on the scenario-based flood modelling, highlighted by the dashed red line.

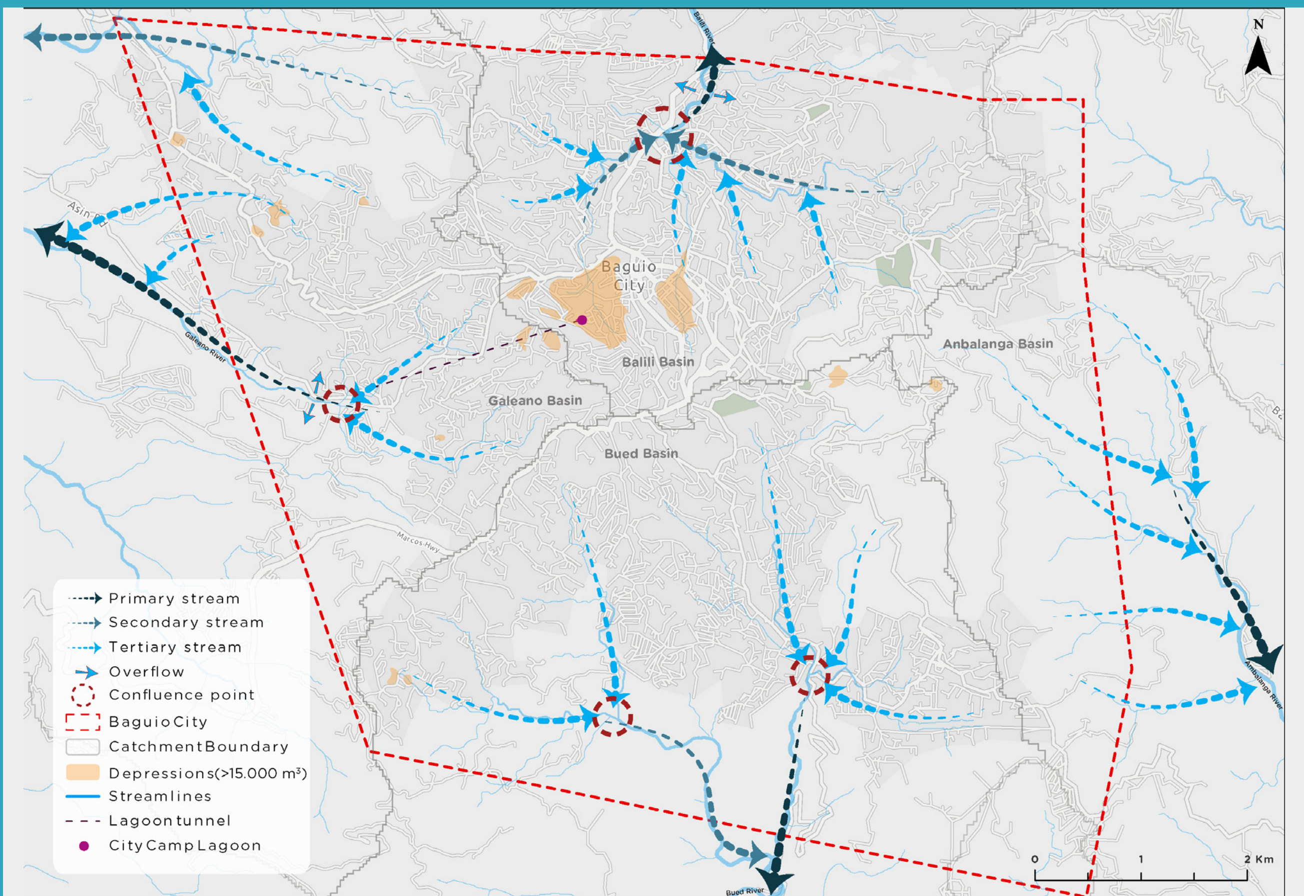


Figure 8: Overall hydrological regime within Baguio City

4.5 RIVER SURVEYS

River surveys have been carried out in the pre-monsoon period of 2021. To do this, a public procurement process was followed, whereby a local company (RASA Surveying) was awarded the contract to implement the scope of works defined by Ramboll. The details of this work can be found in the Technical Note on River Surveys (see Appendix E). The following figures show the extent of the work and the locations of the measured cross-sections.

63 surveyed cross-sections have been used in the river model for Balili. Additionally, interpolated cross-sections have been generated in the model to have enough coupling points in the model. More details about the rivers survey can be found in Appendix E.

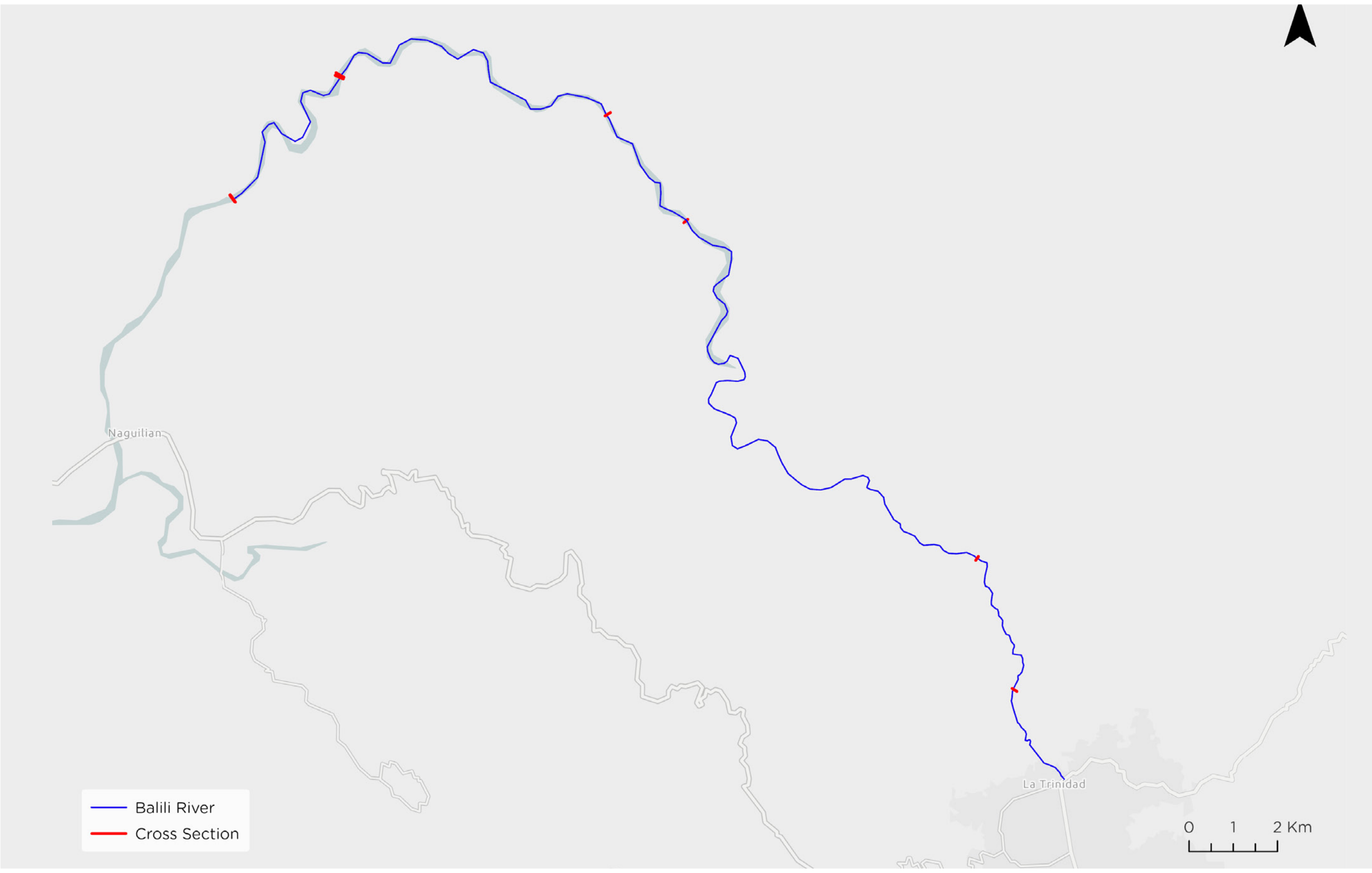


Figure 9: Surveyed cross section locations on the Balili River beyond La Trinidad and up to Mamat-ing Bridge station

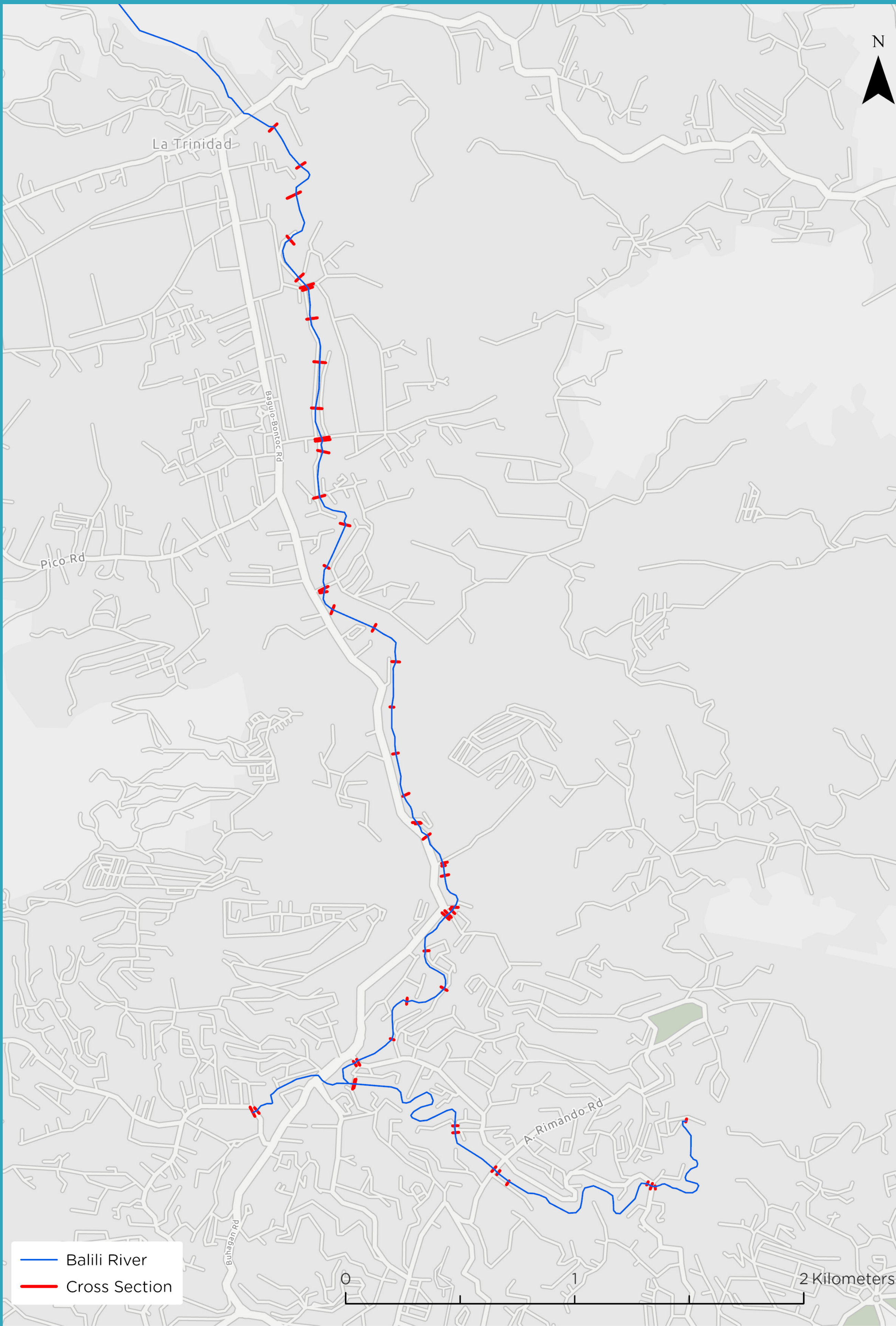


Figure 10: Surveyed cross section locations on the Balili River up to La Trinidad gauging station

4.6 MODELLING SCENARIOS

Modelling scenarios are selected to provide sufficient statistical inputs in the risk assessment and consider both smaller frequent events as well as larger and more rare rain events. While the potential damage from smaller rain events may be more limited, the higher frequency will often make these the main contributor to flood damages over a longer period of time.

The return periods selected for the risk assessment are 3, 10, 20 and 50 years for both existing climate conditions and future climate projections, resulting in a total of 8 modelling scenarios. The 8 modelling scenarios are modelled in each of the four river basin catchments (Balili, Bued, Galiano, Ambalanga), yielding a total of 32 simulations. As described in the baseline report, significant flood damages are observed in Baguio approximately every 3-5 years, hence the smallest event included in this assessment was a 3-year return period rain event.

The scenarios should not be viewed as design service levels, rather the return periods and climate projections are solely selected to provide input for the risk assessment. Four scenarios are deemed sufficient for the assessment of flood risk, taking into consideration the required computational time and benefits of including additional scenarios.

An overview of the scenarios assessed in this report can be seen in Table 7.

Table 7: Overview of model simulations for flood modelling in Baguio

River Basin Model	Model Simulations	Model Scenarios
Balili	8	3-year (Present climate), 3-year (Future climate), 10-year (Present climate), 10-year (Future climate), 20-year (Present climate), 20-year (Future climate), 50-year (Present climate), 50-year (Future climate)
Ambalanga	8	3-year (Present climate), 3-year (Future climate), 10-year (Present climate), 10-year (Future climate), 20-year (Present climate), 20-year (Future climate), 50-year (Present climate), 50-year (Future climate)
Galeano	8	3-year (Present climate), 3-year (Future climate), 10-year (Present climate), 10-year (Future climate), 20-year (Present climate), 20-year (Future climate), 50-year (Present climate), 50-year (Future climate)
Bued	8	3-year (Present climate), 3-year (Future climate), 10-year (Present climate), 10-year (Future climate), 20-year (Present climate), 20-year (Future climate), 50-year (Present climate), 50-year (Future climate)

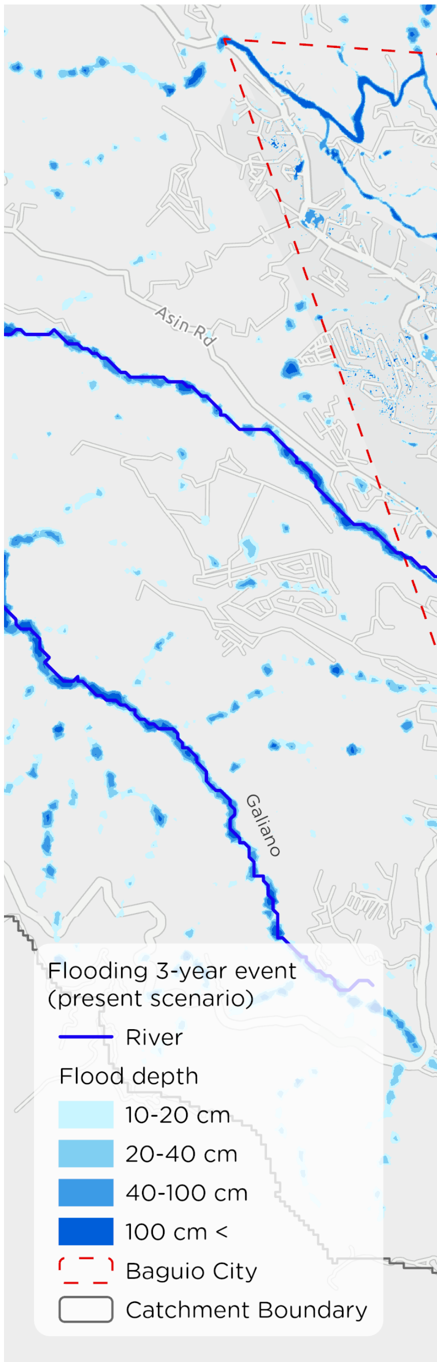
4.7 RESULTS: FLOOD HAZARD MAPS

The primary modelling output considered in this assessment is the maximum flooding extent and depth, both of which are used in the risk assessment. The entire range of flood maps can be seen in Appendix F.

The following maps indicate the flooding extent of both smaller events (3-year return period in current climate conditions) and more rare extreme rain events (50-year return period in projected climate conditions).

Key observation from flooding caused by smaller rain events (3-year return period) are the inundation of natural depressions, in particular in the Balili catchment and scattered more localized flooding in densely built up areas which is likely caused by the lack of drainage and the blocking of natural overland flow paths by structures.

Note that some natural streams are captured directly in the 2D model, and will appear as “flooded”, however this is to be expected and should not be considered a risk.



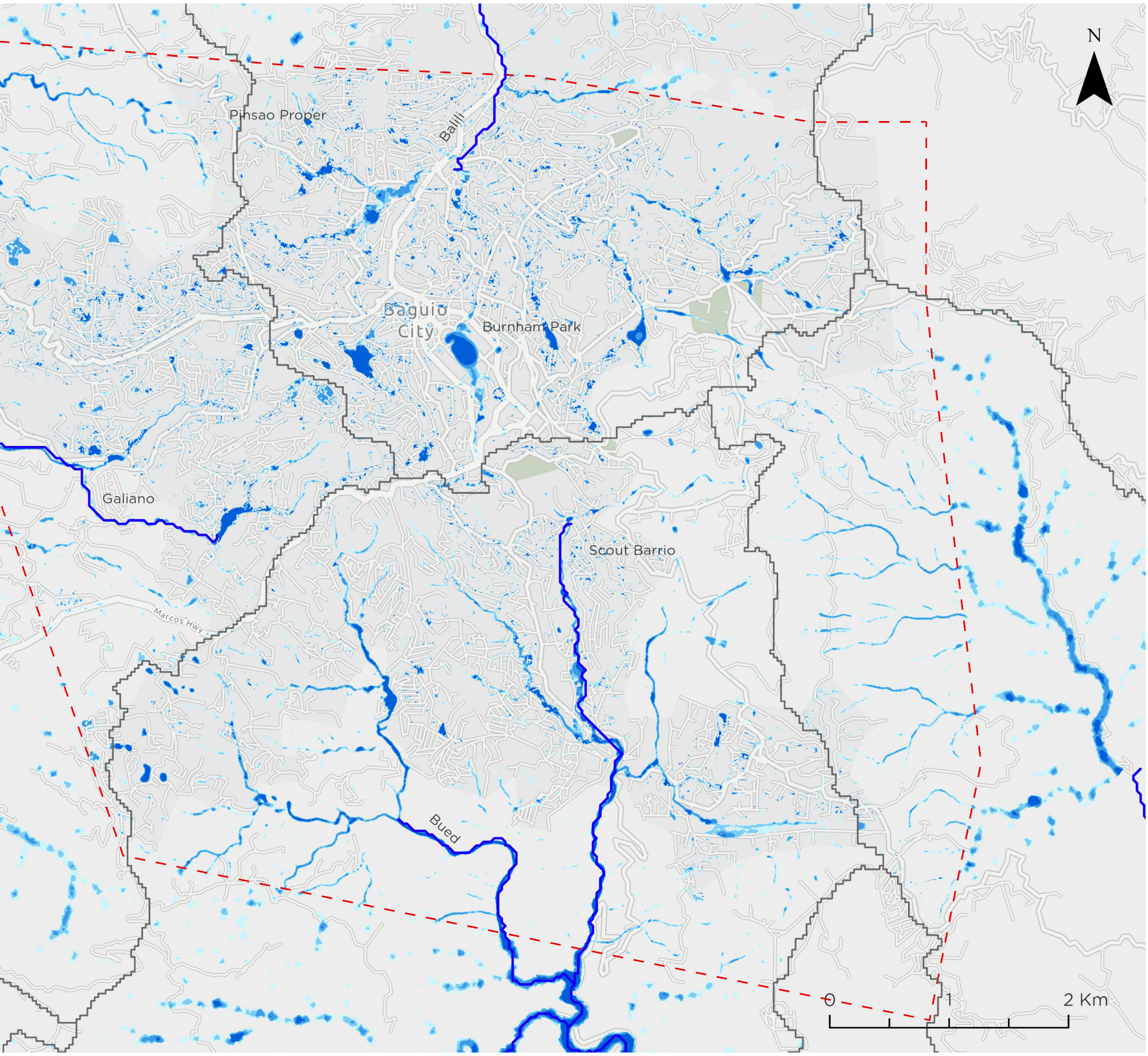
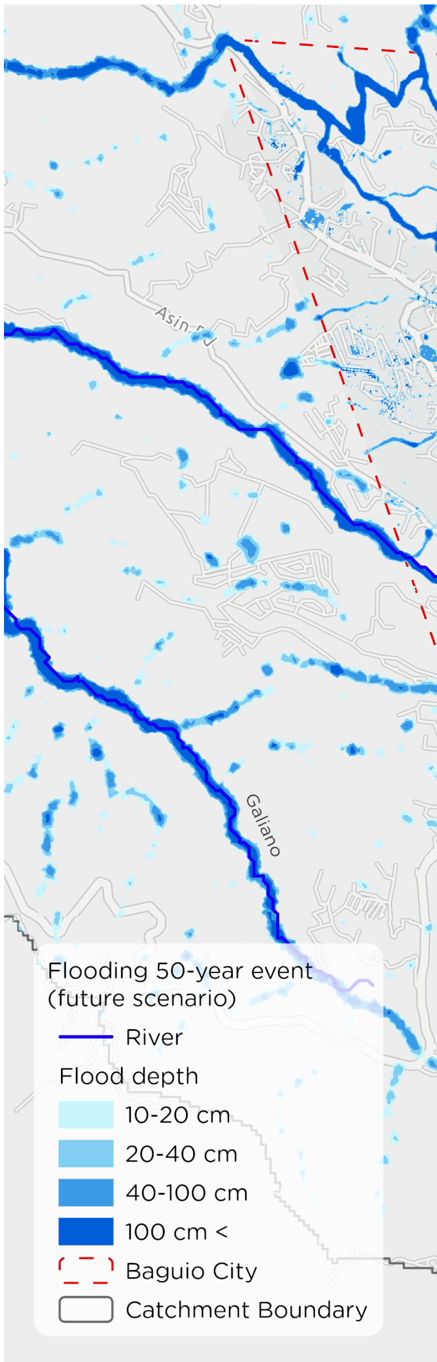


Figure 11: Flooding for a 3-year event under current climate scenario.

As expected, the more intense rain event (50-year return period in future climate conditions) shows a similar pattern of flooding, but more extensive and with higher flood depths. In addition, some of the primary overland flow paths, including roads and alleyways, appear as flooded as the conveyance is no longer sufficient to maintain depths lower than 10 cm. Such inundation is expected to block the roads and affect more houses and infrastructure.



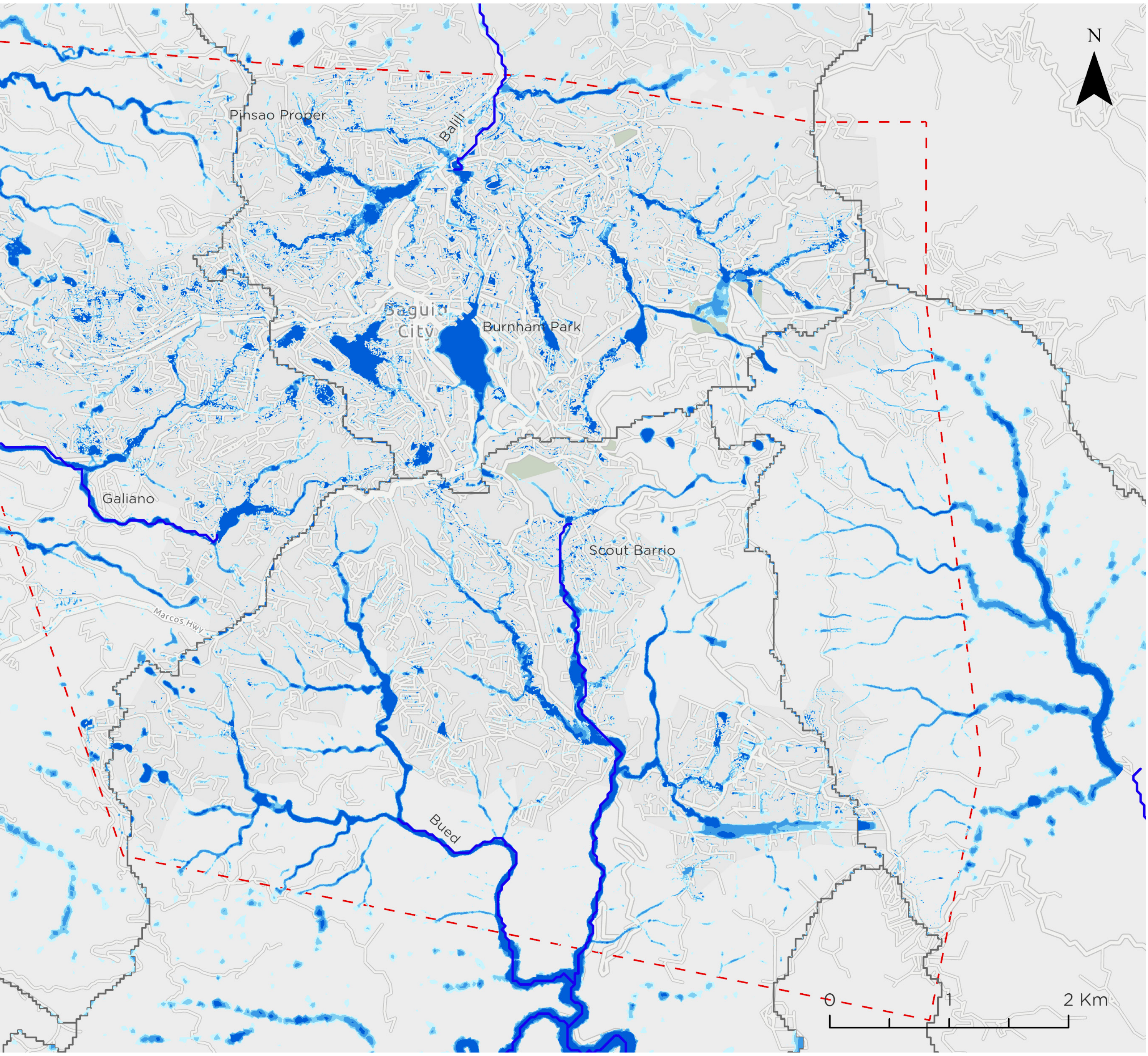


Figure 12: Flooding for a 50-year event under future climate scenario.

Comparison of flooding extent for present and future flooding for a specified return period indicate increase in flooding extent with climate impact due to increase in rainfall, as seen in Figure 13 for a 10-year event and Figure 14 for a 50-year event. Thus, the areas that are exposed to flood hazards will increase in the future. Similarly, areas that are flood prone today are likely to experience even greater impact (e.g. more flood related damages) in the future.

The flood hazard maps show that many houses and roads are exposed to flooding, as seen in Figure 15 for Balili catchment. Flooding is seen to occur on roads, alleyways and near buildings. Buildings and overground structures restrict surface flows and impacts the extent of flooding. Observing the flooding in highly build-up urban areas with narrow alleys, this effect on flooding is evident as shown in the figure below. It is noted that in reality, flooding might enter buildings at a certain threshold and not build up to the water depths indicated by the model. Furthermore, disregarding existing underground infrastructure under the assumption that it is blocked may impact the estimated flooding. Thus, the water depths might be slightly overestimated, which will yield a conservative estimate of flood risk.

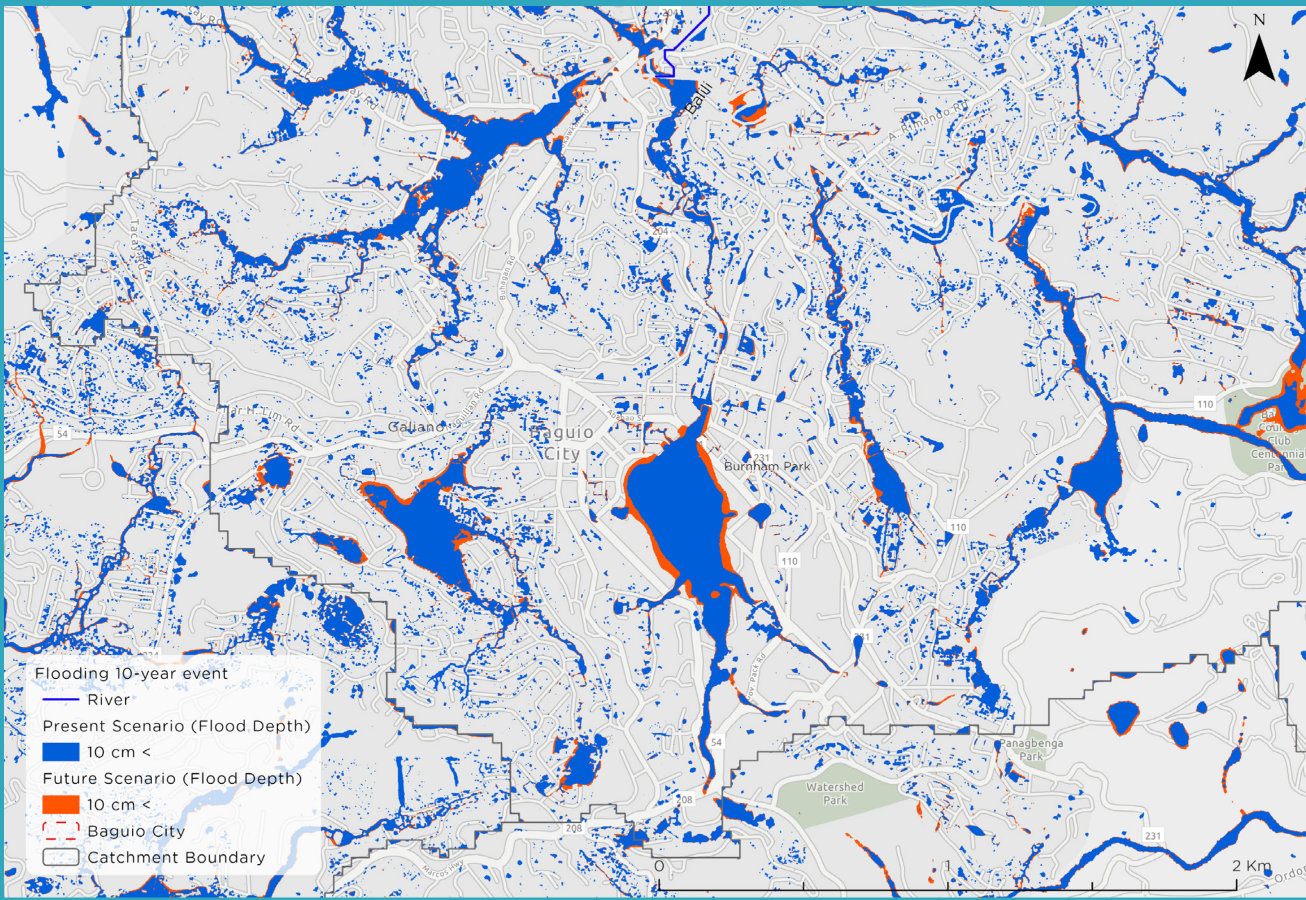


Figure 13: Extent of flooding (greater than 10 cm flood depth) for a 10-year event under future climate scenario.

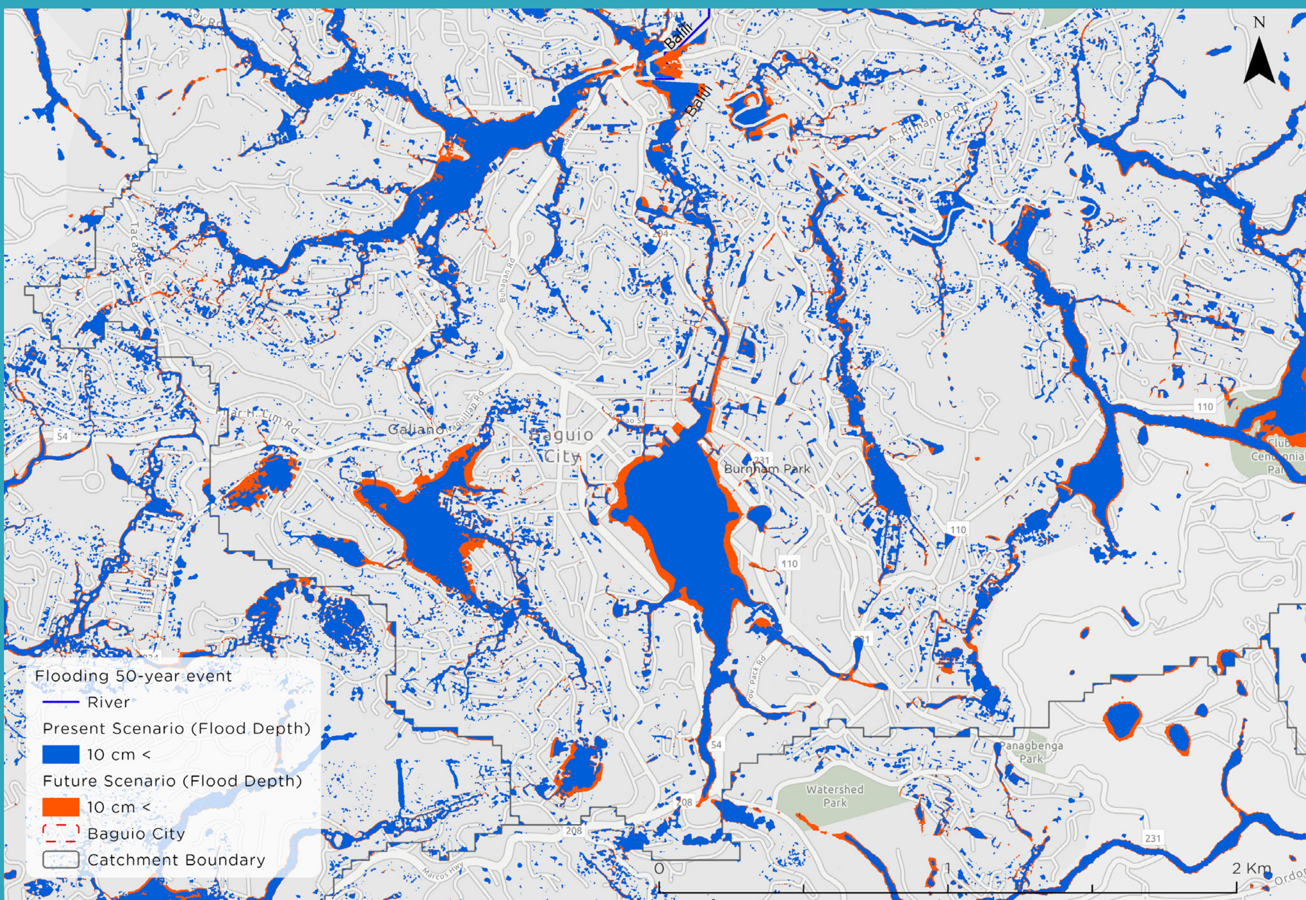
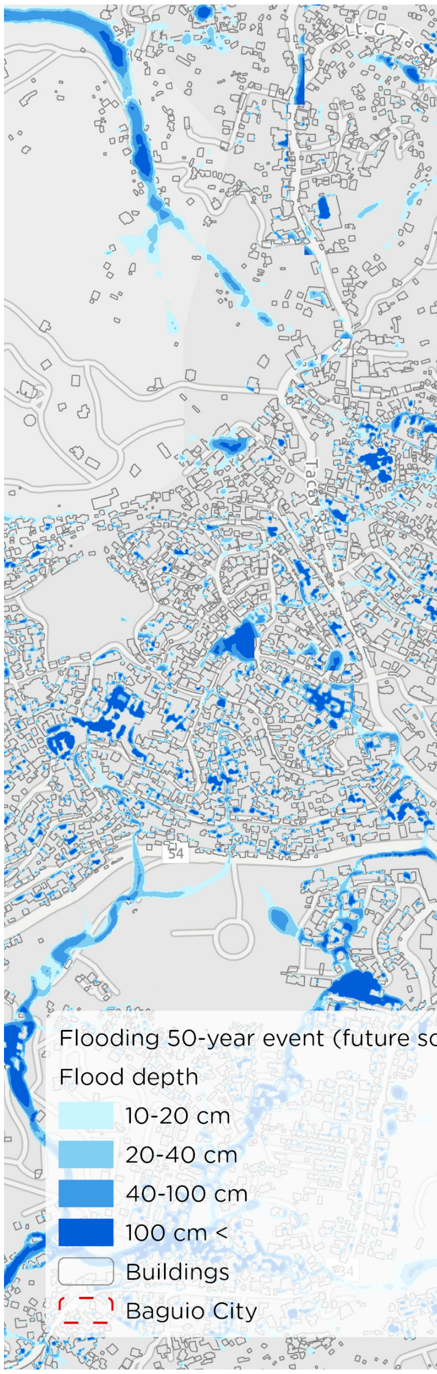


Figure 14: Extent of flooding (greater than 10 cm flood depth) for a 50-year event under future climate scenario.

The exclusion of underground drainage infrastructure in the model could result in overestimation of upstream flooding, as localized ponding could occur at a greater extent and thus downstream flooding could be underestimated as these areas are relieved of runoff. For larger return periods the relative effect on the flooding result is expected to be minimal as the capacity of the underground drainage network is quickly exceeded due to higher rain intensities. By applying a relatively low runoff coefficient of 0.75 in urban/built-up areas, urban runoff has been decreased to account for the conveyance of the drainage infrastructure, however, due to the large gaps in drainage infrastructure data and lack of knowledge on the condition and service level of the drainage system, the influence of the model assumptions on the results is uncertain. Validation of model results by local experts and historical disaster data comparison is undertaken to confirm that areas identified as flood prone based on the flood model results are known to experience flooding, see section 4.7.2.

4.7.1 FLOOD PRONE AREAS

Based on a screening of flooding, flood prone Barangays as well as flood prone localized areas are identified. At a Barangay level, Barangays with high percentage of flooded area (above 10 cm flood depth) for a 3-year present rainfall event were identified. Furthermore, areas with localized flooding were included in the screening. The screening identified 10 flood prone Barangays and 2 localized flood prone areas. The locations of the flood prone areas can be seen Figure 16 and the areas are described in Table 8.



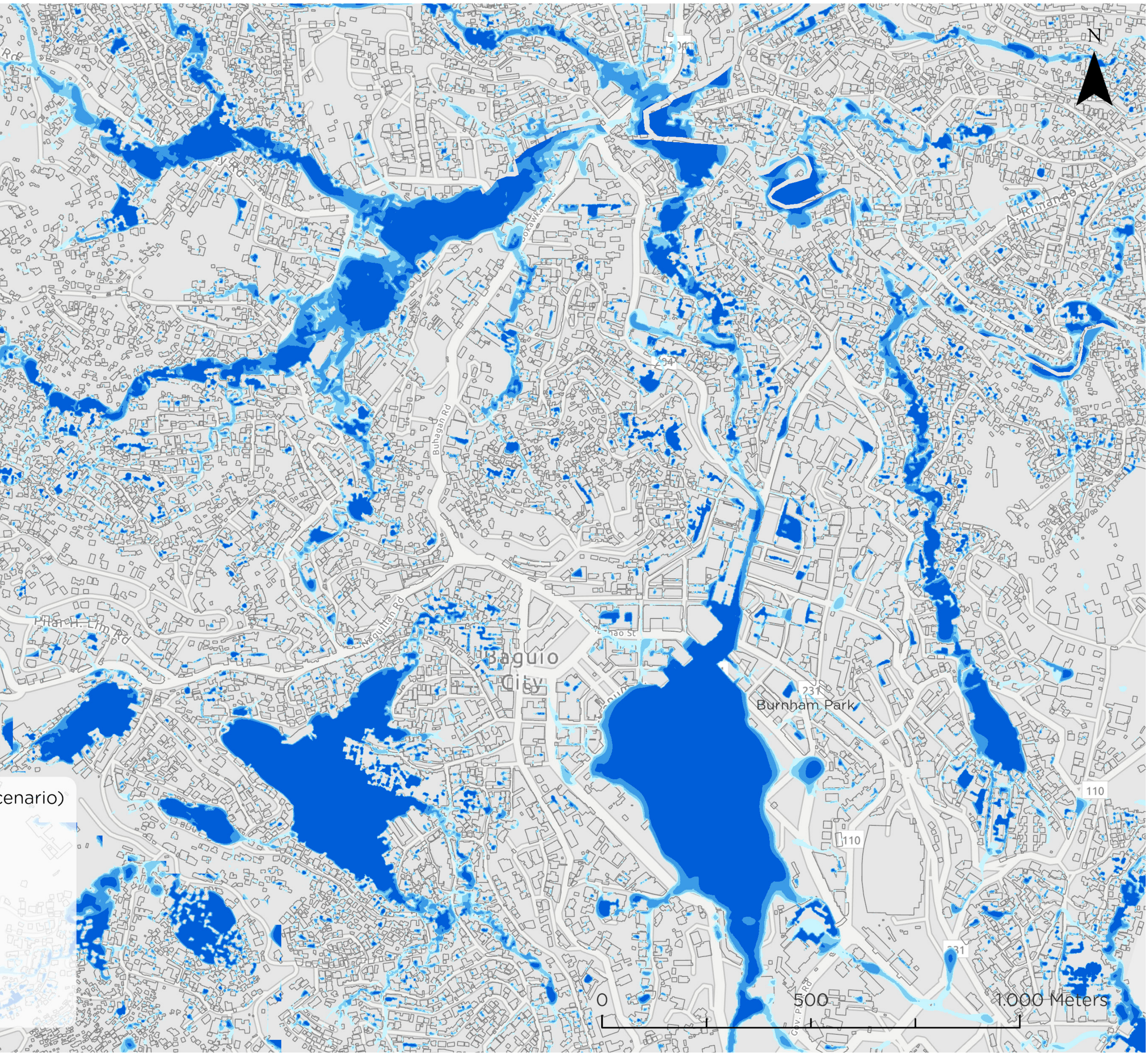


Figure 15: Flooding in densely build-up area in Balili.

The screening shows that many flood prone barangays and areas are located within the Balili river basin, as expected. “Rock Quarry, Lower” and “City Camp Central” located near the City Camp Lagoon are seen to have the greatest percentage of flooded area. Besides the ten flood prone Barangays, flood prone areas are identified at Teachers Camp Compound and near Wright Park. The affected infrastructure within flood prone areas include e.g. roads, buildings, public parks.

The percentage of the catchment flooded (above 10 cm depth) gives an indication of the impact of flooding and is suitable for identification of highly flood prone Barangays. However, the flooded areas should not be taken as the true extent of flooding or used for planning purposes due to model uncertainties. It is noted that the Barangays and areas identified in the screening are not the only areas exposed to flooding as flooding is also observed in other parts of the city. Smaller flooded barangays may have a high percentage of flooding area, whereas larger Barangays with flooded areas may not have a high percentage of flooded area. Additional screening of localized flooding highlights some of these flooded areas on a local scale.

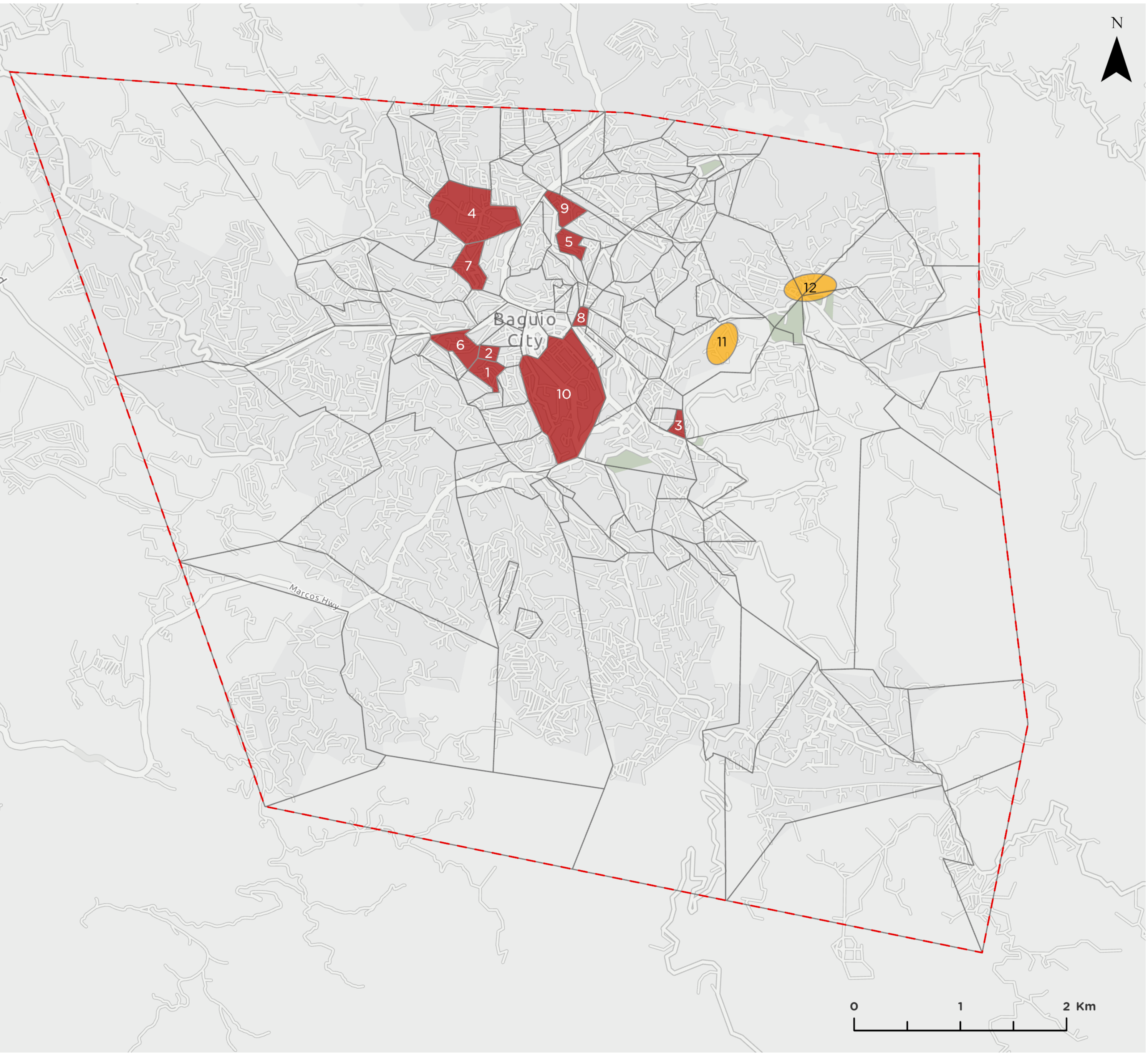


Figure 16: Location of flood prone Barangays and areas with localized flooding.

Table 8: Flood prone Barangays and areas with localized flooding. The number (No.) indicate the location seen in Figure 16. The flooded area is given as the area within the Barangay that is flooded above 10 cm depth.

No.	Name	Area	Flooded area 3-year event (present climate)		Flooded area 50-year event (future climate)	
		[ha]	[ha]	[%]	[ha]	[%]
1	Rock Quarry, Lower	5.8	3.1	52	4.5	77
2	City Camp Central	2.5	0.8	32	1.5	60
3	DPS Area	2.6	0.8	31	1.0	39
4	Guisad Central	32.2	8.4	26	12.9	40
5	Slaughter House Area (Santo Niño Slaughter)	5.1	1.3	25	2.3	45
6	Lourdes Subdivision Extension	8.8	2.1	23	4.4	50
7	Andres Bonifacio (Lower Bokawkan)	9.2	2.1	23	3.3	36
8	Malcolm Square-Perfecto (Jose Abad Santos)	2.0	0.4	22	0.9	46
9	Magsaysay Private Road	6.2	1.4	22	2.5	39
10	Legarda-Burnham-Kisad	62.9	13.0	21	23.3	37
11	Centennial park / Teachers Camp Road	-	-	-	-	-
12	Gilbratar Road / Wright Park	-	-	-	-	-

4.7.2 VALIDATION OF FLOOD RESULTS

The flood results were validated through local experts in LGU and by comparison to historical disaster data for flood events from CDRRMO[9]. A map of the identified flood prone areas (Figure 16) was sent to LGU asking them to confirm whether flooding is known to occur in the identified areas. Additionally, LGU was asked to provide a list of flood prone roads and infrastructure to further verify the flooding results. The anecdotal verification of flood results was documented in email correspondance with representatives from LGU. The historical data from CDRRMO[10] covers almost 20 years (2001 to 2018, with some years missing) and details natural disasters at Barangay level. Together, the anecdotal verification from LGU and the comparison to historical flood distaster data at Barangay-scale are deemed sufficient for validation of the flood results.

LGU confirmed that all flood prone areas identified in the screening are known to experience flooding. Additionally, the following critical infrastructure within the identified Barangays and areas is known to experience frequent flooding according to descriptions by LGU:

- Guisad-Ferguson Road
- DPS Interior Roads
- Sto Nino Slaughter Road
- Easter Road connecting to Ferguson Road
- Lourdes Subdivision Road
- Lake Drive connected to Kisad and going to Malcolm Square Area (ongoing rehabilitation of drainage infrastructure at Lake Drive Area)
- Teachers Camp Compound

The flood model results show flooding at or near the infrastructure described as flood prone by local experts. The exception is Lourdes Subdivision Road which does not appear flood prone based on the flood model results. This illustrates the model uncertainty and could indicate that flooding is not caused by surface flows, but rather exceedance of the drainage network capacity, which is not explicitly included in the flood model setup. The ability of the flood model to capture flooding at historically observed flood prone roads and infrastructure further validates the model results and their feasibility for flood risk mapping.

9, 10 Disaster Risk Reduction and Management Office (CDRRMO), 2020, Disaster data analysis” Baguio City.

As part of the Baseline assessment, disaster data from CDRRMO[11] including flood events in Baguio City was assessed. The data covers the years from 2001 to 2018 (with some years missing data) and includes the number of people and number of houses affected due to flooding at the Barangay level, as well as the number of flooding events recorded. The historical disaster data confirms that “Rock Quarry, Lower” and “City Camp Central” are known to be highly flood prone, as these Barangays have the highest recorded number of people affected by flooding. A total number of 6 flooding events was recorded for “Rock Quarry, Lower” affecting a total of 2676 people, the highest number of flooding events and affected people recorded for a Barangay in Baguio. In “City Camp Central” a total number of 5 flooding events was recorded affecting a total of 2210 people. The data also shows a record of flooding events for “Guisad Central” and “Legarda-Burnham-Kisad” with one flooding event recorded for each Barangay. The disaster data does not show a record of flooding events for the remaining Barangays identified as flood prone in the flood model results. As described in the Baseline assessment, there are some gaps in the disaster data as it was not possible to obtain data for all years within the timeframe assessed. Furthermore, the quality of the data for the recorded years is uncertain. Thus, it is not possible to conclude whether the discrepancy in the historical record compared with the modelled flood prone areas is due to model assumptions or gaps in disaster data. However, based on historical observations and anecdotes by experts from LGU the modelled flood prone areas are expected to be exposed to flooding.

The extent of flooding near the city camp lagoon area is seen to be large, even for events of smaller return period as seen in Figure 18. The City Camp Lagoon is drained by the lagoon tunnel, which is not included in the model. Thus, the flooding depth and extent might be overestimated by the model. The City Camp Lagoon is located in a large natural depression and at extreme rainfall events, large volumes of water will reach the area. The drainage capacity of the lagoon tunnel may be exceeded at peak intensities of extreme events resulting in great extent and depth of flooding. Local descriptions of historically observed flooding in the area confirms that this seems to be the case.

11 Disaster Risk Reduction and Management Office (CDRRMO), 2020, Disaster data analysis” Baguio City.

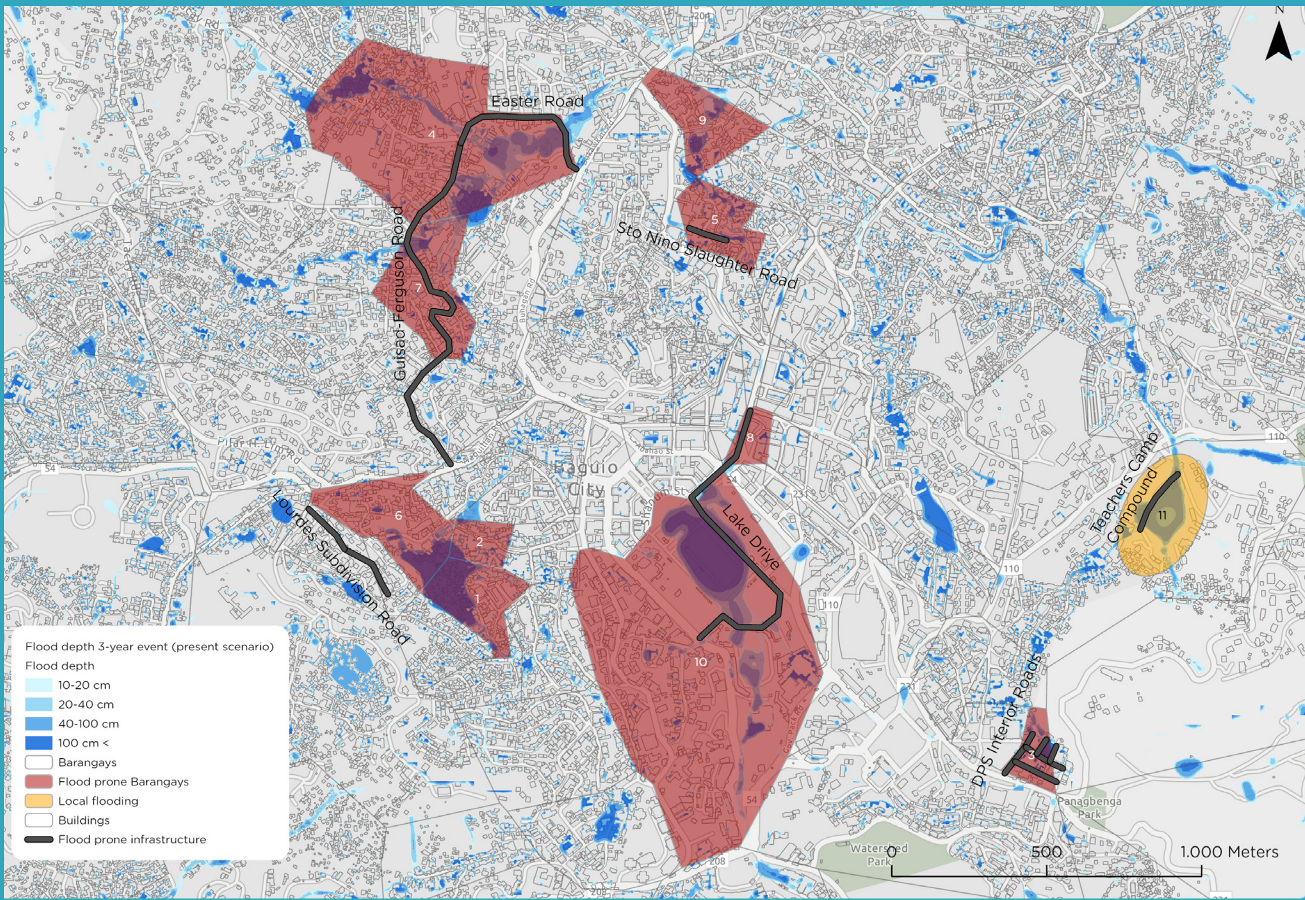


Figure 17: Flood prone infrastructure according to locally anchored descriptions based on historically observed flooding. The flood prone Barangays and localized flooded areas have been identified through a screening of flood model results.

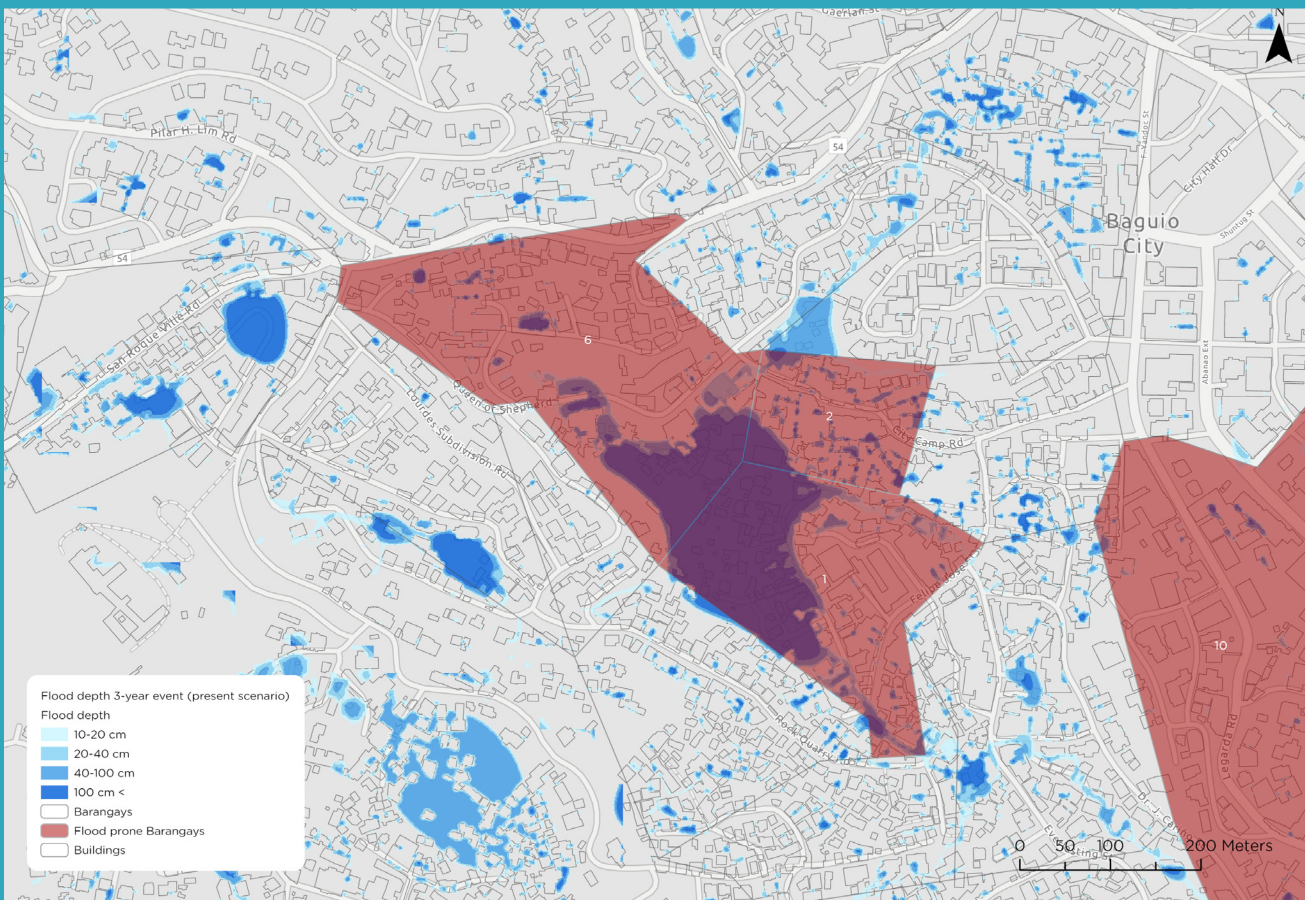


Figure 18: Flooding near the City Camp Lagoon, located in Rock Quarry Lower (1).

5. LANDSLIDE ASSESSMENT

Figure 19: Landscape, Baguio
Source: Ramboll (picture taken on site by Consultant Team)

This section describes the landslide hazard assessment forming part of the overall hazard assessment in Baguio. All technical details can be found in Appendix C. This section of this report deals primarily with the key findings.

Landslides are initiated in sloped areas due to rainfall and subsequent water saturation and destabilization of topsoils. Other causes include earthquakes. The effect of earthquakes on landslides is increased if topsoils are water saturated. The landslide susceptibility can furthermore be increased by human factors such as extra load from buildings, roads, heavy duty traffic, etc.

The hazard assessment is based on the factors influencing soil destabilization including topography, rainfall, geology, hydrogeology, and earthquakes as well as latest research and data on landslide susceptibility, both regional and locally in Baguio.

5.1 KEY FINDINGS

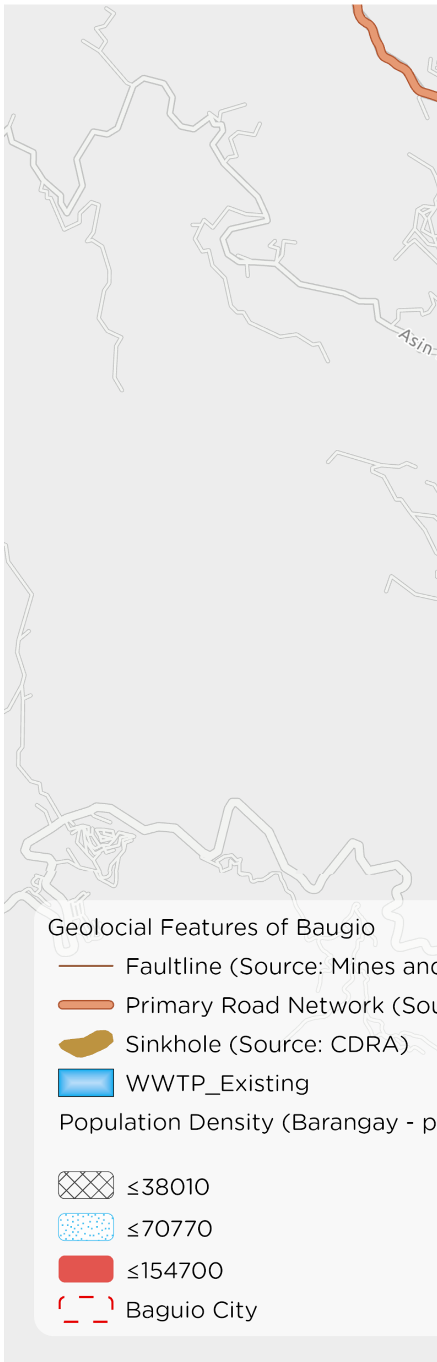
5.1.1 BAGUIO'S GEOLOGY AND HYDROGEOLOGY

Baguio City varies between moderately sloped to very sloped terrain, which makes the soils more prone to erosion if not stabilized by vegetation or other measures. The topsoils in Baguio are developed from weathered bedrock and consists of Bakakeng Sandy Loam, Mirador Clay Loam and Tacdian Loam[12]. The thickness of topsoil layers is not big and will typically be biggest in depressions due to soil movements, making water flow towards lowest topographies. The topsoil is fragile and at risk of being exposed and eroded if not covered by vegetation. It is only the top layer that consists of loam with organic content making it suited for vegetation growth. If the topsoil is eroded, the subsoil does not have properties that support plant growth.

12 Comprehensive Land Use Plan, [Online]. Available: Baguio https://www.baguio.gov.ph/planning-and-development/downloadable-forms, [Accessed April 2021].

Baguio City has many geological fractures, with their main orientation being NNW/SSE (Mirador, Burnham, Bued River and Loakan faults), and with alternating fractures (San Vicente Fault) orientated NW/SE. The fractures cut through several bedrock formations, as shown in Figure 20, which also shows the location of sink holes, "grouped" in bands with the same orientation as the fractures indicating that the formation of sink holes is related to the orientation of the fractures. In the Baguio city area earthquakes will be amplified in the fracture zones where tension in the bedrock is released.

Topsoils will infiltrate water to deeper layers until underlying layers (weathered bedrock sub soils and fractures) are water logged. The intact topsoil has a relatively low permeability and thus low infiltration rates. In general, there are clear limitations to the groundwater drainage in Baguio, as the capacity for groundwater transport in the system, including topsoil, subsoil and bedrock, has either low permeability or limited groundwater capacity. This means that the hydrogeological system in Baguio sets some constraints which likely put the city at risk of frequent soil saturation and subsequent destabilization unless otherwise stabilized or efficiently drained with surface drain solutions. In this regard, Nature-based Solutions (NbS) can be highly relevant to look at in Baguio, as an alternative drainage paradigm for surface water management.



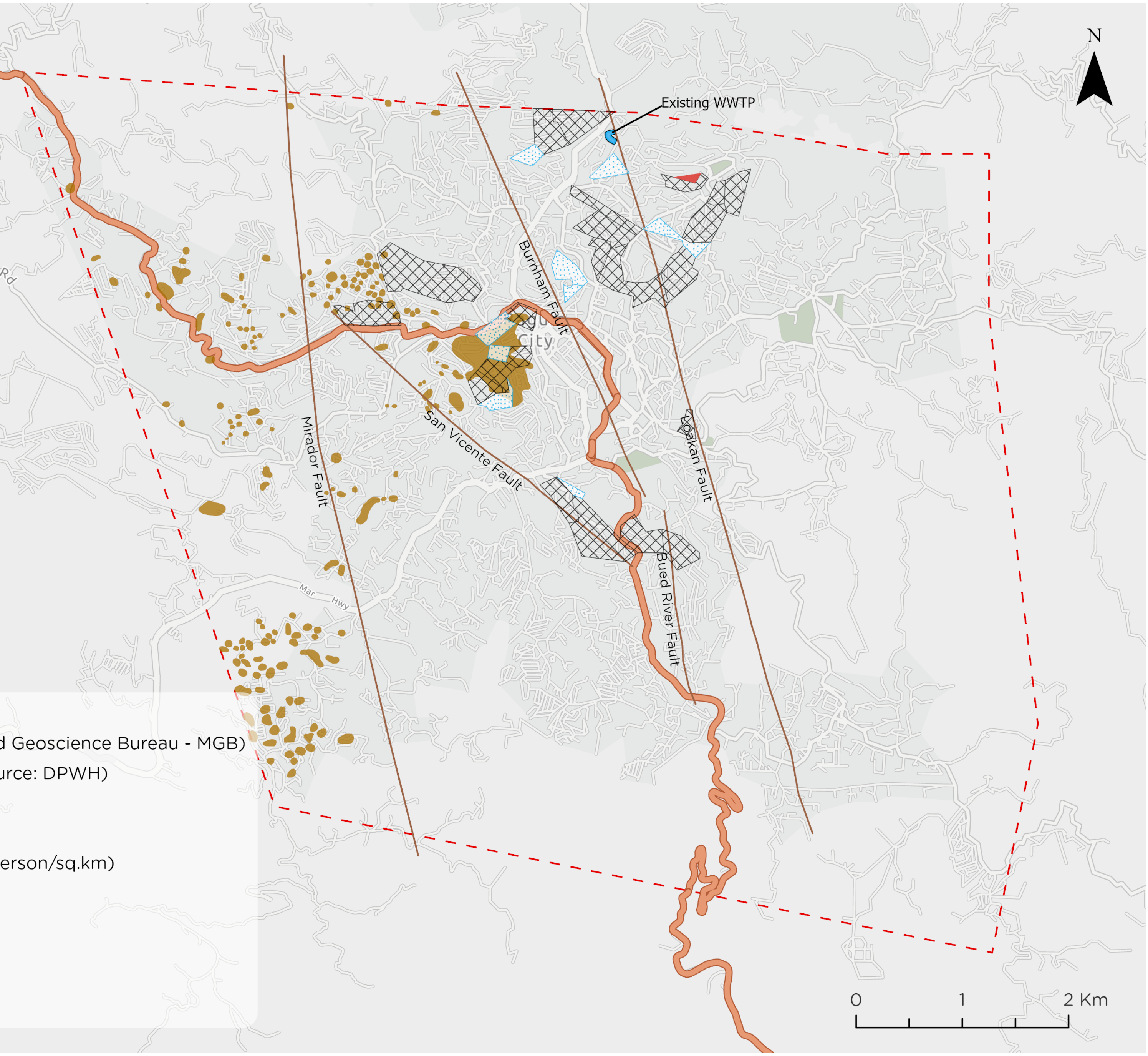


Figure 20: Bedrock geology, Baguio

5.1.2 HAZARD ASSESSMENT

The topsoil in Baguio was previously more stable due to a natural vegetation cover with extensive consolidated root systems[13]. Land development due to increased population has resulted in destabilization of the soil. Natural vegetation covers have been removed or in some cases replaced with shallow rooted grasses, leaving the soil exposed to erosion and landslides.

The main causes for landslides are earthquakes and/or heavy rainfall. Earthquakes especially affect the city areas situated on top of the unstable fault lines. Landslides are likely to occur in these areas during earthquakes. The susceptibility for landslides initiated by earthquakes is increased during the rainy season where the soil is water saturated and thereby less stable. In this sense, a deeper assessment of concurrent risks in Baguio would be highly relevant, to gain a deeper understanding of how these two hazards interact with each other.

Recent studies[14] show that landslides are not only controlled by the rainfall during cloudbursts/typhoons but also to a large degree by antecedent "normal" rainfall events. Previously, the perception was that accumulated rainfall of more than 500 mm would cause landslides. The new study[15] however suggests that 2,600 mm rain need to accumulate for landslides to occur. The study shows that areas with antecedent rainfall are more vulnerable to landslides than areas with no antecedent rainfall even though the cloudbursts in the latter areas are heavier. In general, the landslide susceptibility is increased significantly if the cloudburst follows a period of 2 weeks of normal rain – even though the rainfall is not necessarily heavy. The main factor is the soil saturation before the cloudburst. Large cloudbursts with no antecedent rainfall rarely lead to landslides.

13 Comprehensive Land Use Plan, [Online]. Available: Baguio https://www.baguio.gov.ph/planning-and-development/downloadable-forms, [Accessed April 2021].

14, 15 C. Abanco; G.L. Bennett; A.J.,Matthew; M.A. Matera; F.J. Tan, The role of geomorphology, rainfall and soil moisture in the occurrence of landslides triggered by 2018 Typhoon Mangkhut in the Philippines, 2020, Natural Hazards and Earth System Sciences, ed. 259.

5.1.3 LANDSLIDE SUSCEPTIBILITY MAPPING

The highly landslide susceptible areas are located in the sloping areas between the two plateaus and at the rim of the city to the west, south and east. The low to moderate landslide susceptible areas consist of approx. 20% of the city area. The remaining area of the city has either high or critically high landslide susceptibility. See Figure 21.

The sloping area between the two plateaus coincides with the San Vicente Fault, which can increase the destabilization of the soils. Areas sloping to the northwest or southeast show more frequent landslides[16]. This is coincident with the overall orientation of the fractures (Figure 20) and is probably caused by the increased groundwater flow in the fractures during heavy rain. The groundwater will typically surface in the sloped areas along the fractures. A higher susceptibility in these areas is not evident from Figure 21, it but should not be ignored in future landslide mitigation measures.

Building from the flood hazard map presented in the previous section (see Figure 12), it is apparent that Baguio's main drainage areas are the sloping areas to the northwest (Balili catchment) and to the southeast following the overall topography. There is no significant drainage from north to south over the slope in the center of the city between the two plateaus. See Figure 22.

To the northwest and southeast (see Figure 22), it can be assumed that the drainage is adding instability to a soil that would already be unstable due to slope and rainfall alone. The drainage direction is coinciding with the direction of the fault system (NW-SE), where fault zones contain bedrock that is crushed and therefore able to infiltrate surface water and transport it downhill as shallow groundwater until it resurfaces and creates a very unstable top soil. This scenario is realistic for the main drainage areas to the north-west and south-east of Baguio, creating areas where soils are wetted from both above and below.

16 C. Abanco; G.L. Bennett; A.J.,Matthew; M.A. Matera; F.J. Tan, The role of geomorphology, rainfall and soil moisture in the occurrence of landslides triggered by 2018 Typhoon Mangkhut in the Philippines, 2020, Natural Hazards and Earth System Sciences, ed. 259.

The sloping area, along the San Vicente fault, between the two central plateaus in the city center, does not show any surface drainage pathways. In the upper north plateau, accumulation and flooding is seen. As the area is flat, this does not affect the landslide susceptibility, but it can affect the sloping areas between the plateaus. Limited runoff/drainage will increase the infiltration and thereby destabilize the topsoil. Over a period of rainfall, the soil in topographically flat areas tend to saturate sooner than sloping areas. The upper plateau flood "ponds" are close to the landslide susceptible area and when the soil water saturation "reaches" the slope – it will become unstable and prone to landslides.

5.2 LANDSLIDES WARNING

5.2.1 EARLY WARNING SYSTEMS

For a warning system, it is, as described in the sections above, important to incorporate both the typhoon forecast as well as antecedent rainfall and relate them to areas of high landslide susceptibility.

The following 3 methods can be considered for a landslides early warning system for Baguio:

1. Rainfall monitoring
   The landslide warning can be based on a flood early warning system monitoring of accumulation of antecedent rainfall. Studies show that accumulation of 500 to 2600 mm of antecedent rainfall during the rainy season is necessary for landslides to occur[17]. This can vary from site to site and will depend on local topsoil characteristics and drainage. Antecedent rainfall combined with typhoon forecasts will initiate landslide warnings.

17 Baguio City Ecological Profile, 2018. [Online].
Available: https://www.baguio.gov.ph/sites/default/files/city_planning_and_development_office/downloadable_ forms/Ecological%20Profile%202018%20%28Chapter%203%29.pdf.; [Accessed April 2021].

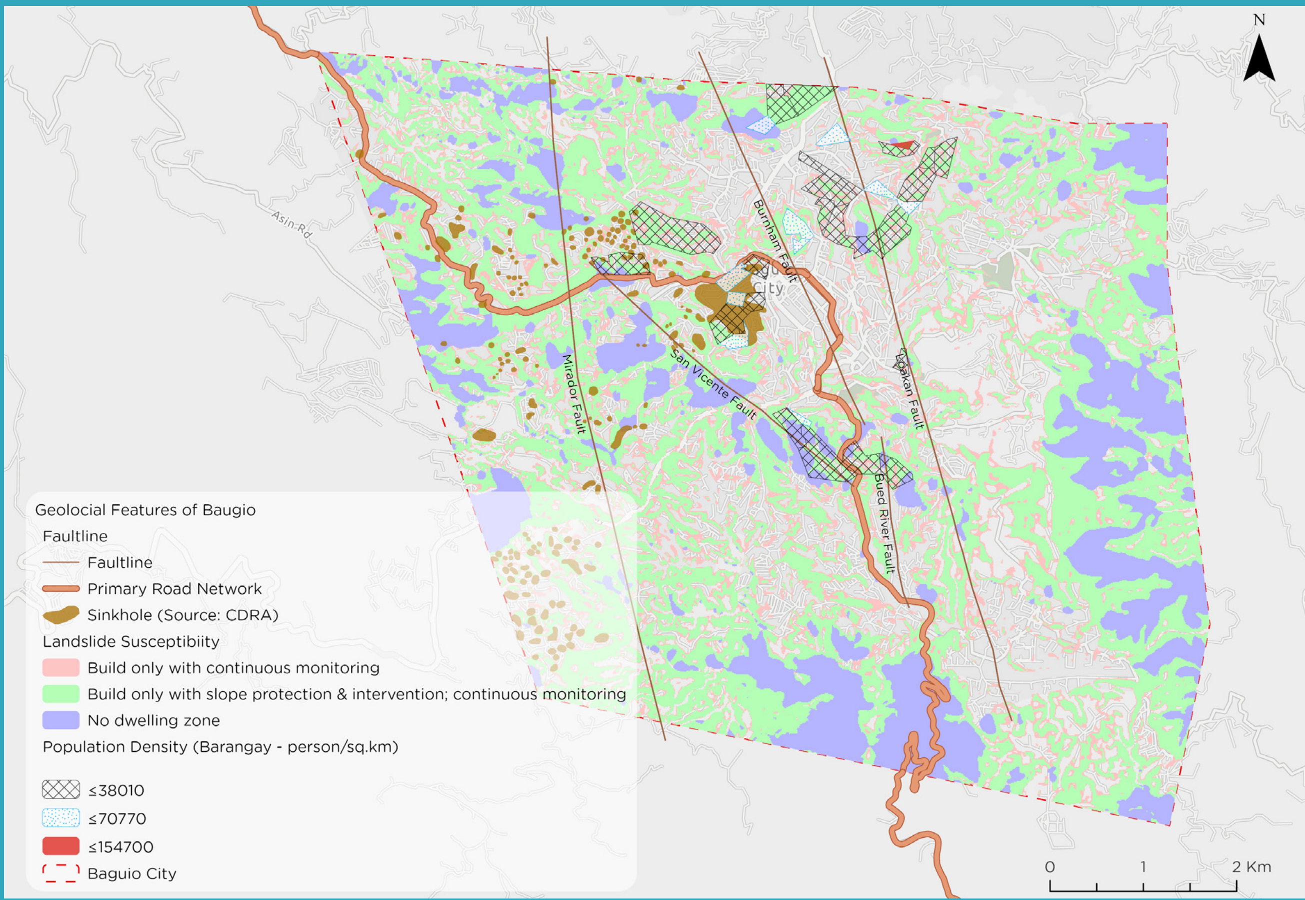


Figure 21: Landslide susceptibility, Baguio

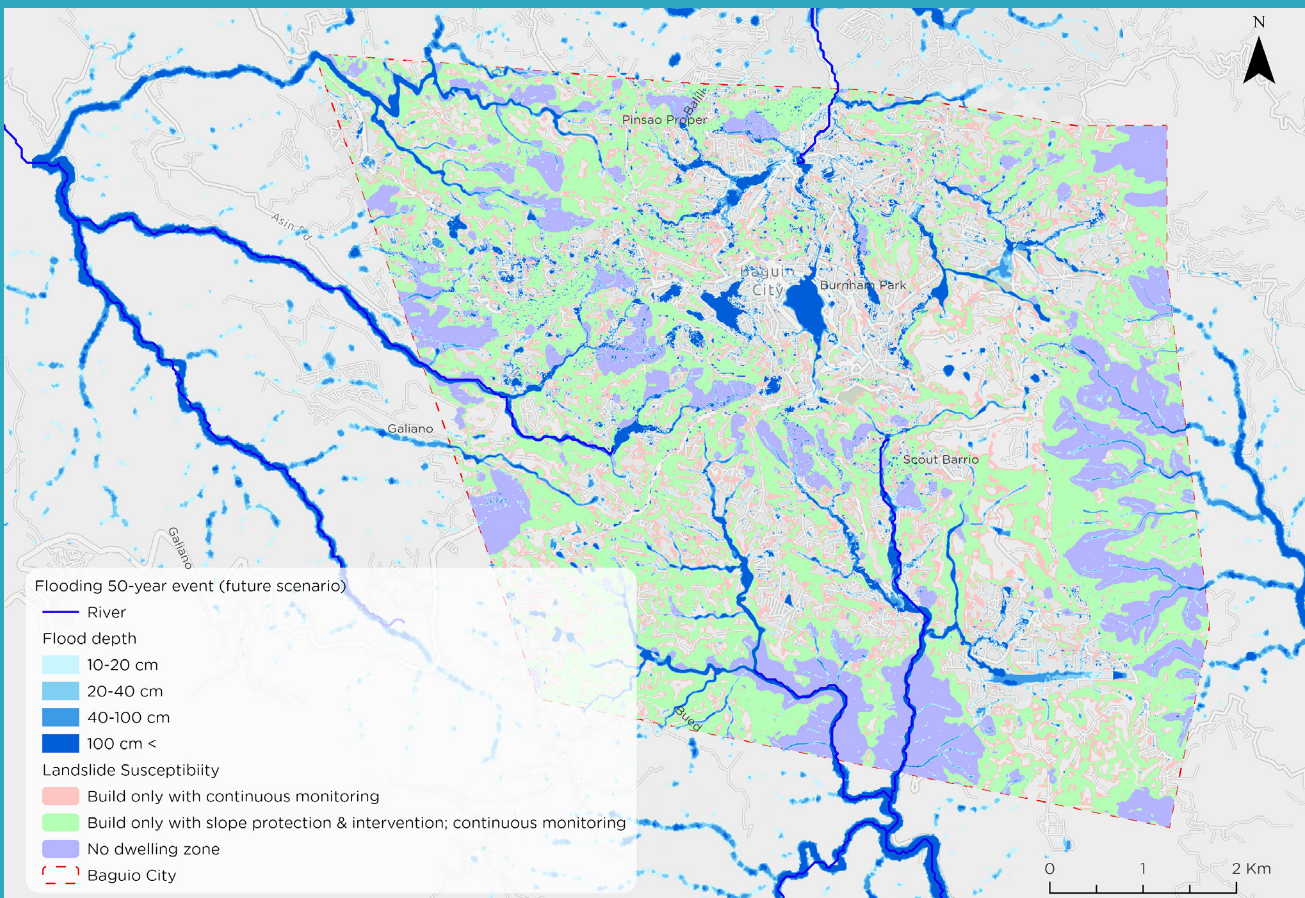


Figure 22: Flooding for 50-year event in the future climate scenario and landslide susceptibility

The uncertainty of the method is the precise correlation between rainfall and soil moisture.

2. Satellite monitoring
   Satellite data can estimate the soil moisture.
   Previous studies show that they must be used with caution and that satellites do not necessary adequately capture the conditions on the ground[18,19].

3. Real time soil moisture measurements
   The most direct way to estimate the landslide susceptibility is to take topsoil samples and determine the water content. For the clayey and sandy loams in Baguio, the topsoils will typically be saturated and prone to landslide when the water content reaches 30-45%. It is simple to establish the water content of the soil by drying the sample and measure the weight difference. The method should be applied in the areas of most landslide susceptibility.

   The difficulty of the method is that it is labor intensive due to sampling at landslide susceptible areas and following laboratory work.

18 Hilario, Flaviana and Guzman, R. and Ortega, D. and Hayman, Peter and Alexander, Bronya, 2009, El Nino Sourthern Oscillation in the Philippines: Impacts, Forecasts and Risk Management, Philippine Journal of Development, vol. 36, pp. 9-34.

19 D. Kirschbaum and T. Stanley, 2018, Satellite based Assessment of Rainfall Triggered Landslide Haxzard for Situational Awareness, Earth's Future, 6, 505-523.

Out of the 3 above mentioned methods to support a warning system the rainfall monitoring approach is recommended due to its ease of application and its direct correlation to the flood early warning system being setup for Baguio.

5.2.2 RAINFALL DATA FOR EARLY WARNING:

Accumulated rainfall data
A landslide threshold at 2600 mm is suggested based on Baguio City Ecological Profile[20]. Another study suggest that the threshold is 500 mm[21]. Beyond the threshold the top soil will be close to saturated and therefore susceptible to landslides even from smaller rain events. In order to set up a conservative alarm threshold that is activated before landslide events, this project suggest an alarm threshold below 500 mm for antecedent rainfall. Using the less conservative value of 2600 should be preceded by detailed local investigations of soil rainfall and soil destabilization.

Typhoon forecasts
The threshold for typhoon rainfall forecast will be calculated based on the size of the antecedent rainfall. The threshold is defined by the time when the sum of the antecedent rainfall and the predicted typhoon rainfall within 2 weeks exceeds the saturation point estimated at 500 mm (see above) within the rain season.

20 Baguio City Ecological Profile, 2018. [Online].
Available: https://www.baguio.gov.ph/sites/default/files/city_planning_and_development_office/downloadable_ forms/Ecological%20Profile%202018%20%28Chap-ter%203%29.pdf.; [Accessed April 2021].

21 L. Nolasco, D. Javier and Kumar, 2018, Deriving the rainfall threshold for shallow landslide early warning during tropical cyclones: a case study from northern Philippines, National Hazards, 90, 921-941.

6. FLOOD RISK ASSESSMENT

Figure 23: After Typhoon Ketsana (Ondoy), 26 September 2009
Source: Asian Development Bank

This section describes the key aspects in the development of the flood risk assessment, where a detail GIS-based process has been implemented, in close consultation with the LGU and taking as point of departure the work carried out through the Climate and Disaster Risk Assessment (CDRA). The LGU's CDRA followed national guidelines provided by the Department of Human Settlements and Urban Development (DHSUD). The national guidelines are founded on the UN Framework Convention on Climate Change.

All technical details can be found in the Appendix D. This section of this report deals primarily with the key assumptions, constraints, and findings.

6.1 SUMMARY ON THE CDRA

Following the national guidelines, "risk" in the CDRA is defined as the product between likelihood of occurrence and severity of consequences. The LGU assessed five exposed elements: Population, urban use areas, natural resource-based production areas, lifeline utilities, and critical-point facilities. In each element, one or more types of assets were assessed, e.g. lifeline utilities include water pipelines, electrical lines, and roads, while urban use areas include areas for commercial use, slaughter house, planned unit development, cemeteries, and the airport.

In the CDRA each exposed asset was assessed individually and assigned an individual scoring from 1 to 6 on likelihood of occurrence and an individual scoring from 1 to 4 on severity of consequences[22]. The LGU reported the process of individual scoring of assets on multiple parameters to be very taxing and impractical. The LGU also raised concerns about the national guidelines sometimes being irrelevant or unsuitable for the City of Baguio.

Furthermore, from the guidelines, the LGU received from DHSUD it's understood that the guidelines follow now outdated terminology from IPCC Assessment Report 4 from 2007[23], where vulnerability is defined as the product between impact and adaptive capacity.

22 NEDA, HLURB, UNDP, 2012, Reference Manual on Mainstreaming Disaster Risk Reduction and Climate Change Adaptation in the Comprehensive Land Use Plans Report, HLURB, Manila.

23 IPCC, The Intergovernmental Panel on Climate Change, 23 April 2021. [Online]. Available: https://www.ipcc.ch/.

6.2 APPROACH AND METHODOLOGY

Ramboll will adhere to the climate risk guidelines from IPCC Assessment Report 5, and risk will henceforth be defined as the product between hazard (given by frequency and exposure) and vulnerability, see Figure 24 (ADB guidelines are also updated to follow IPCC AR5[24]).

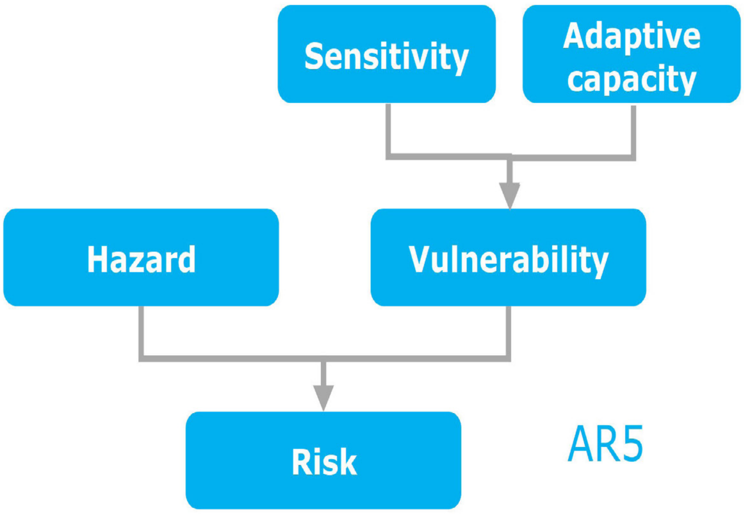


Figure 24: IPCC AR5 guidelines for climate risk assessments.

24 ,25 WW. Ian, G. Anthony, M. Ian and D. Guillaume, 2020, Practical Guide to Integrated Flood Risk Management (TA 9634-REG: Strengthening Integrated Flood Risk Management), Landell Mills Ltd, Wiltshire.

As part of this project, Ramboll performs hydrodynamic simulates and identifies flood prone areas in relation to several rainfall return periods. This hazard information on exposure and probability of occurrence will be incorporated in the Risk Assessment and replace the scoring of likelihood of occurrence, i.e. instead of scoring each exposed asset 1 to 6 by reviewing historic data, exposure is assessed through modelled probabilities.

Not only does the hydrodynamic modelling make the hazard piece in the risk assessment statistically and technically sounder, but it also yields a city-wide exposure and probability assessment now, and in the future, instead of only assessing historically exposed assets.

To assess the consequences of climate related hazards, the CDRA scored assets individually on a scale of 1 to 4 on severity of consequences. As stated, Ramboll will instead assess the consequences as the vulnerability of assets as a product of adaptive capacity and sensitivity.

Another very notable difference is that in this project Ramboll will score types of assets instead of scoring assets individually, i.e. all hospitals are assigned the same score, all commercial areas are assigned the same score, etc. By scoring types of assets, the process becomes much more streamlined and easier to reproduce when new data become available in the future (e.g. updated climate scenarios or updated CLUP).

Naturally, some detail on asset level is lost, but for a city-wide risk assessment the benefits of streamlining heavily outweigh the benefits of assessing assets individually.

6.3 FLOOD HAZARD ANALYSIS

The hazard piece of the risk assessment is based on the results from the hydraulic modelling. For two points in time (present and future) four flood layers are available for the baseline scenario, i.e. status conditions: 3-year event, 10-year event, 20-year event, and 50-year event.

It's assumed that there are no considerable damages for events smaller than the 3-year event. While there will still be considerable damages for events larger than the 50-year event, the largest contributors to annual damages (risk) are typically seen in events between ~10-30 years. These events still have considerable exposure to cause much damage plus very high probabilities. Figure 25 shows a theoretical example of summing several return periods to risk and how the largest events are not the largest contributors to the annual damages. This is why Ramboll has chosen four relatively small return periods for the risk model.

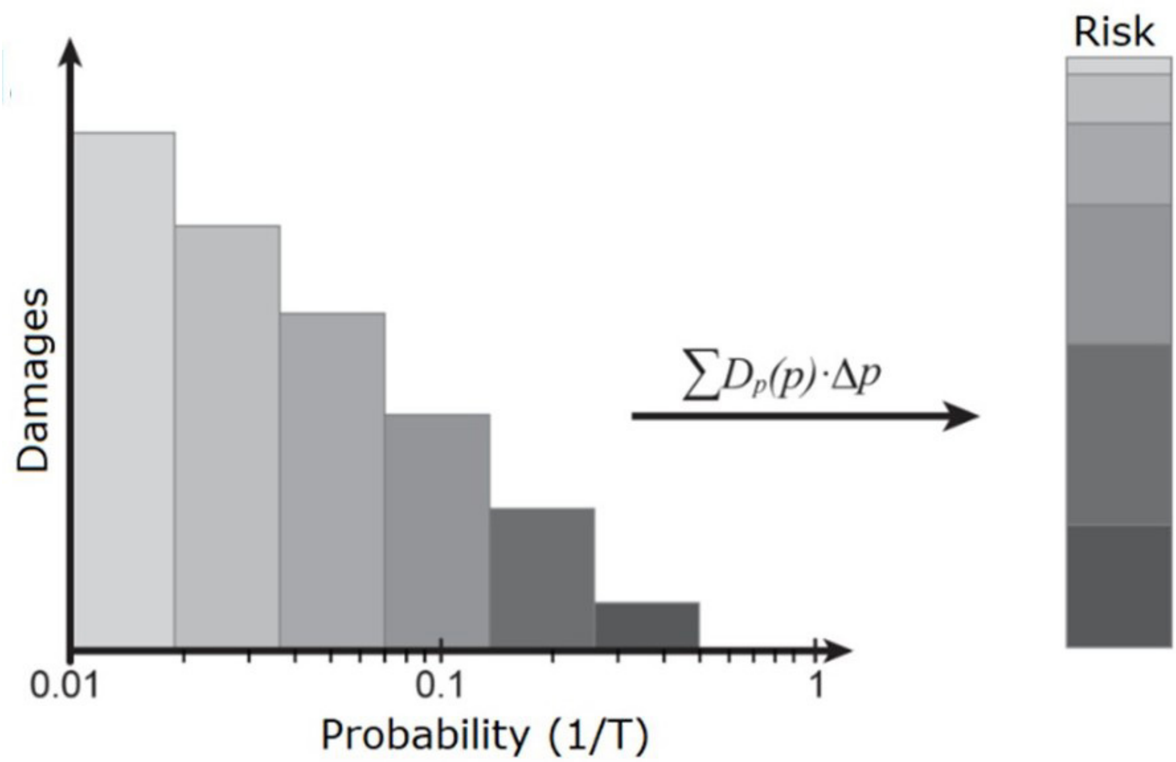


Figure 25: Illustration of summing return periods over probability. Though damages are largest at the largest event, it's not the largest event that contributes the most to the annual damages (risk)[26].

26 A. S. Olsen, G. G. Dalgaard, B. Paludan, O. Mark, A. Laustsen, J. J. Linde, C. Jakobsen, K. Friis, M. Hundahl, D. Rosbjerg, P. S. Mikkelsen and K. Arnbjerg-Nielsen, 2017. Metoder til bestemmelse af serviceniveau for regnvand på terræn, Spildevandskomiteen, Skrift nr. 31, IDA Spildevandskomiteen 2017, Copenhagen.

6.4 FLOOD VULNERABILITY ANALYSIS

As seen in Figure 24 vulnerability is a product of adaptive capacity and sensitivity. To assess adaptive capacity, Ramboll incorporates the scoring scheme of adaptive capacity as presented in the CDRA, which is a three-step scale from low to high adaptive capacity. A more detailed scale description and scoring of all asset types can be found in Appendix D.

As there is no scoring scheme in the CDRA for sensitivity specifically, the scoring of this parameter will draw on other information in the CDRA. In the CDRA, potential impact is assessed as a product between exposure and sensitivity. As such, the difference in impact and sensitivity lie in whether an asset is exposed or not and the scoring scheme of impact can be moderated to score sensitivity as well. As such sensitivity of asset types is also scored on a three-step scale from low to high sensitivity. A more detailed scale description and scoring of all asset types can be found in the Technical Note on Risk Assessment.

The results of the vulnerability analysis can be seen in Table 9.

Table 9: Vulnerability scoring of types of assets in the Flood Risk Assessment

Theme	Asset	Adaptive capacity score	Sensitivity score	Vulnerability score	Vulnerability
Population	Residential R1 (low density residential area)	1	1	1	Low
	Residential R2 (medium density residential area)	1	1	1	Low
	Residential R3 (high density residential area)	1	2	2	Low
	Building footprint	2	2	4	Moderate
Urban use areas	Commercial areas	2	2	4	Moderate
	Slaughterhouse	3	3	9	High
	Planned unit development	1	1	1	Low
	Airport	3	3	9	High
	Informal settlement	3	3	9	High
Natural resource-based production area	Watersheds and reservations	3	1	3	Low
	Park areas	1	1	1	Low
	Cemetery areas	2	1	2	Low
	Forest areas	1	1	1	Low
Critical facilities	Barangay halls	1	2	2	Low
	Bridges	1	1	1	Low
	Fire stations	1	2	2	Low
	Police stations	1	2	2	Low
	Government facilities	2	2	4	Moderate
	Public schools (primary and secondary)	2	3	6	Moderate
	Tertiary education	2	3	6	Moderate
	Health centres and hospitals	3	3	9	High
	Evacuation centres	2	3	6	Moderate
	Cultural sites	3	1	3	Low
Lifeline utilities	Primary electrical lines	2	1	2	Low
	Secondary electrical lines	2	1	2	Low
	Pipelines	3	1	3	Low
	Utilities zones	3	2	6	Moderate
	National roads	3	2	6	Moderate
	City roads	2	1	2	Low
	Circumferential roads	2	1	2	Low
	Barangay roads	2	1	2	Low

6.5 MODEL SETUP

In the risk model all assets listed in Table 9 are overlayed with flood results from the hydraulic models. In the risk model three parameters are essential: Inundation threshold for damages, area threshold for damages, and whether or not an asset is fully flooded or not when both thresholds are crossed.

The inundation threshold is a defined water depth at which damages occur to an exposed asset, and the area threshold is a definition for how much an area must be flooded for damages to incur. More information on these two parameters can be found in Appendix D.

Final parameter to consider is whether or not an asset is regarded as fully flooded when both above-mentioned thresholds are crossed, or only partially flooded based on actual flooded area. I.e. if a park is 50 % exposed, does the full vulnerability score incur or only 50 % of the score? As this risk assessment is based on a multi-criteria assessment where vulnerability scoring is independent of asset size, all exposed assets are considered fully flooded to incur the full vulnerability score. The disadvantage of this approach is that assets which cover large areas such as forests and parks may contribute to a higher risk in regions that aren’t exposed. To accommodate this, results will be shown with flood layer. The risk results are still valid to identify exposed assets and combined with the flood layer, the location of potential mitigation measures can be identified.

6.6 RESULTS: FLOOD RISK MAPPING

Based on the flood layers modelled for present and future conditions, present and future risk are assessed. Present risk is shown in Figure 26, and future risk is shown in Figure 27. It’s important to note that damages do not increase with inundation, and more inundated areas do therefore not carry more weight for that reason.

The risk labelling follows the same risk scoring as in national guidelines, where three levels of risk were classified: Low (score 1-4), medium (score 5-10), and high (score 11-24). To identify most at-risk areas in this assessment the class “high” has here been split into two classes, and the maps therefore have four classes: Low (1-4), moderate (>4-10), high (>10-15), and very high (>15-24). As maximum cell values in some cases were greater than 24, all cell values are normalised based on maximum value in current conditions to a maximum value of 24.

Generally, most risks in both current and future conditions are found around the city centre, and the northern and eastern parts of the city, as this is more densely populated and therefore have more critical assets, roads, schools, etc.

Table 10 summarises the sizes of the areas at risk in current and future conditions. More than 60 % of the city is at risk of flooding (based on areas covered by low to very high risk). As expected from the flood layers where more areas become exposed in the future, the total area size of areas at-risk increases in the future, albeit not very much, from 61 % to 62 %. As evident in the flood layers, the extent of flooding doesn’t increase much in the future, and as noted earlier, the risk model is independent of inundation depths (as long as the inundation threshold is crossed). Therefore, as the exposure to flooding increases only slightly, so does the risk.

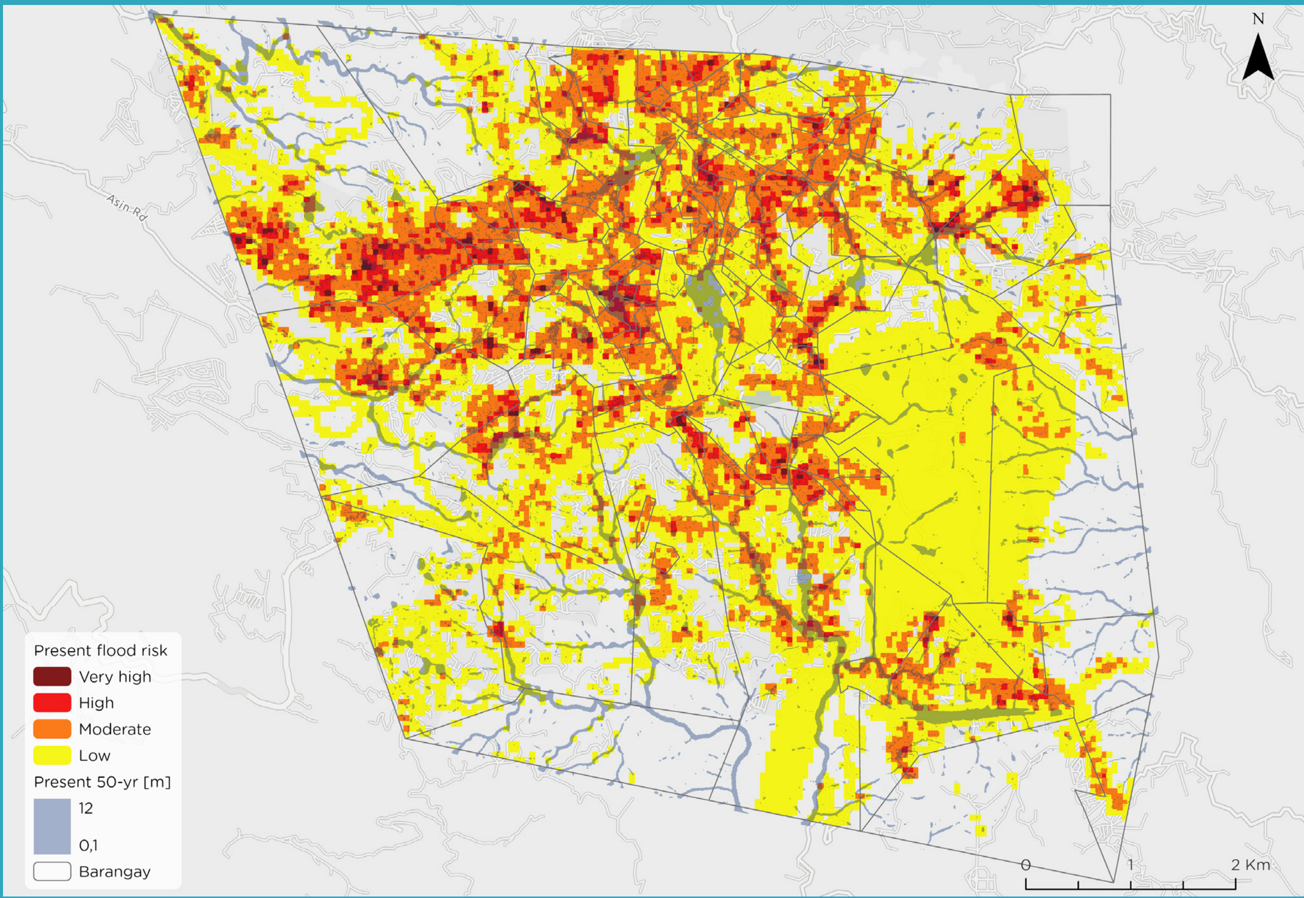


Figure 26: Map of present flood risk based on asset vulnerability and modelled flood hazard.

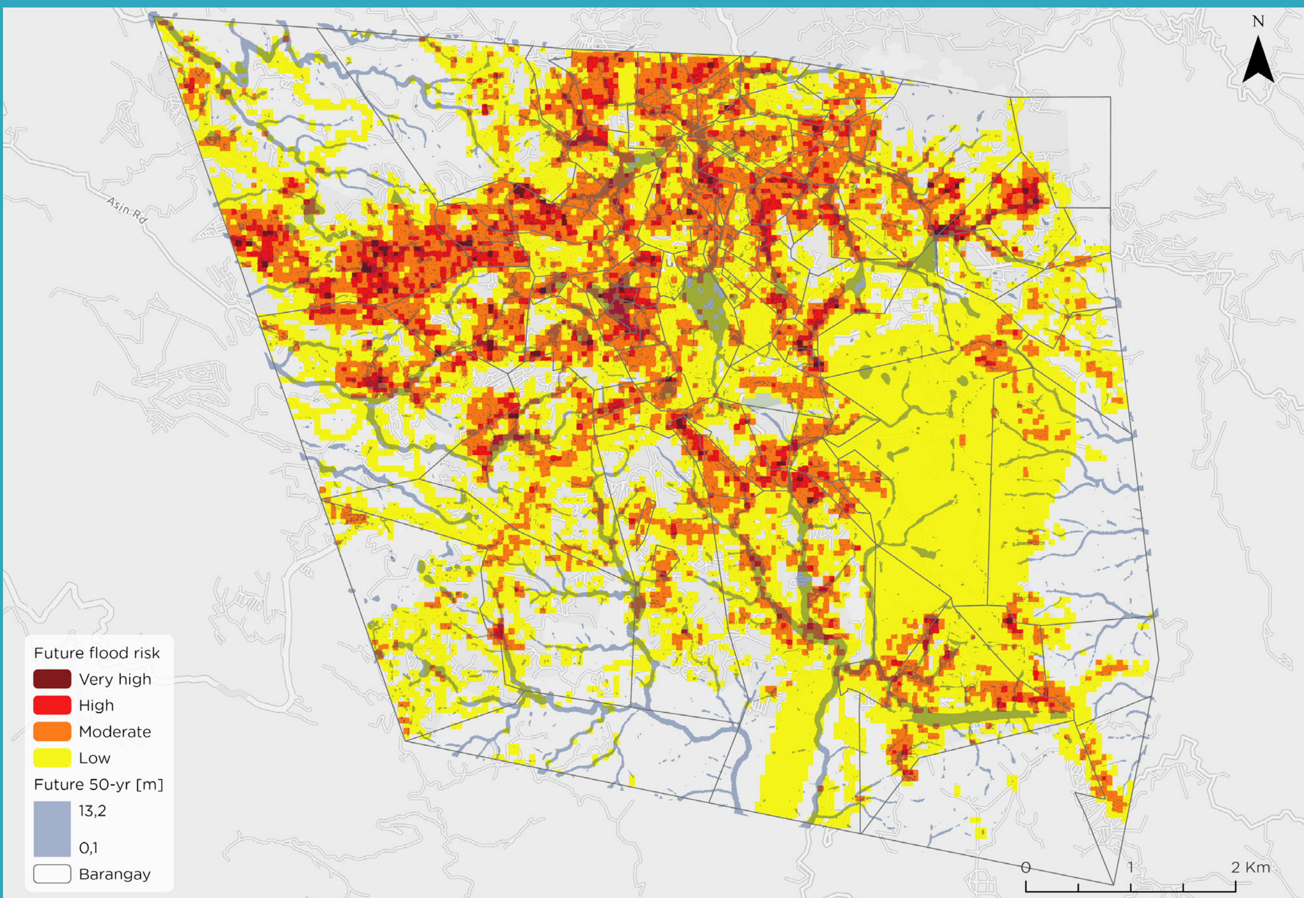


Figure 27: Map of future flood risk based on asset vulnerability and modelled flood hazard.

Table 10: Sizes of areas at risk in current and future conditions

	Size of area at risk in current conditions [ha]	Size of area at risk in current conditions [% of total city area]	Size of area at risk in future conditions [ha	Size of area at risk in future conditions [% of total city area]
Very high risk	19	0.33	23	0.40
High risk	208	3.61	242	4.21
Moderate risk	987	17.18	1007	17.52
Low risk	2286	39.78	2285	39.77
Next to no risk	2247	39.10	2190	38.11

As identified in the CDRA some of the most at-risk barangays in current conditions are City Camp Central and the surrounding barangays. Other at-risk barangays are Fairview Village, Padre Zamora, Balsigan, Gabriela Slang, Poliwes, southern areas of Irisan, Victoria Village, Santo Ninõ Slaughter, Padre Zamora, Honeymoon, Lopez Jaena, and Quirino Hill.

By calculating the size of areas at high or very high risk within in each barangay and comparing the result with the total area size of the barangay, the barangays can be ranked according to most at-risk based on barangay area.

In present conditions the top 10 barangays most-at risk based on percentage area are:

- City Camp Central 75 % of barangay at high or very risk
- Balsigan 60 % of barangay at high or very risk
- San Antonio Village 58 % of barangay at high or very risk
- Santo Niño Slaughter 51 % of barangay at high or very risk
- Rock Quarry, Lower 50 % of barangay at high or very risk
- Victoria Village 49 % of barangay at high or very risk
- DPS Area 47 % of barangay at high or very risk
- Gabriela Silang 47 % of barangay at high or very risk
- Kayang Extension 40 % of barangay at high or very risk
- City Camp Proper 37 % of barangay at high or very risk

In future conditions the top 10 barangays most-at risk based on percentage area are:

- City Camp Central 85 % of barangay at high or very risk
- Balsigan 60 % of barangay at high or very risk
- San Antonio Village 58 % of barangay at high or very risk
- Santo Niño Slaughter 53 % of barangay at high or very risk
- Rock Quarry, Lower 52 % of barangay at high or very risk
- Gabriela Silang 50 % of barangay at high or very risk
- Victoria Village 50 % of barangay at high or very risk
- DPS Area 47 % of barangay at high or very risk
- Honeymoon 40 % of barangay at high or very risk
- Kayang Extension 40 % of barangay at high or very risk

See map in Figure 28.

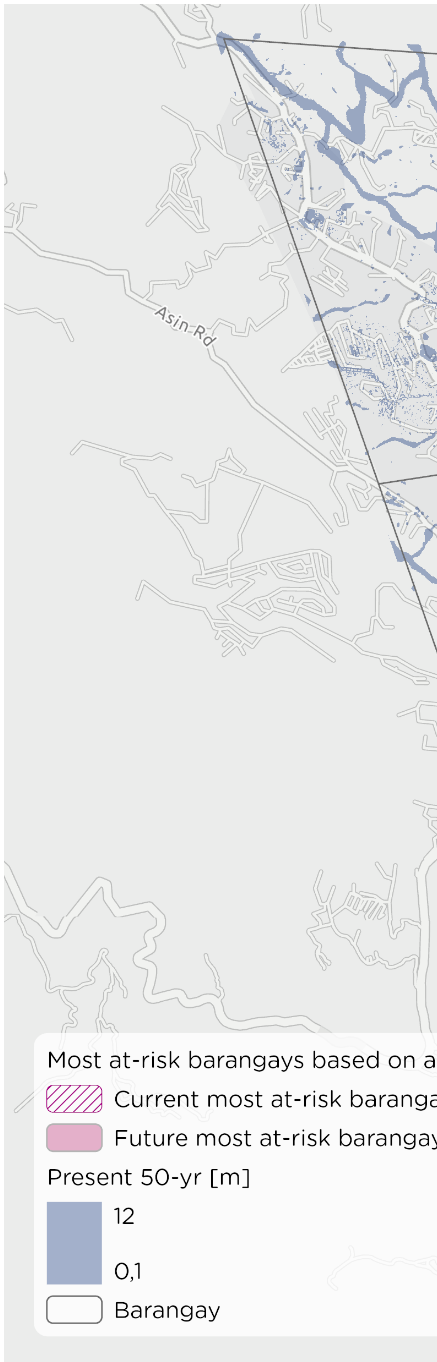
It’s worth noting that ranking barangays on percentage area affected tends to “favour” smaller barangays, that are densely populated and don’t have large park areas, large industrial sites, etc. Considering only the size of areas with high or very high risk, the top 10 most at-risk barangays in present conditions are:

- Irisan 48 ha (8 % of total area)
- San Luis Village 10 ha (11 % of total area)
- Fairview Village 10 ha (31 % of total area)
- Gibraltar 9 ha (13 % of total area)
- Balsigan 8 ha (60 % of total area)
- Pinget 8 ha (16 % of total area)
- Asin Road 7 ha (4 % of total area)
- Loakan Proper 7 ha (3 % of total area)
- Bakakeng Central 6 ha (3 % of total area)
- Victoria Village 6 ha (49 % of total area)

In future conditions the top 10 barangays most-at risk based on area are:

- Irisan 58 ha (10 % of total area)
- San Luis Village 12 ha (12 % of total area)
- Gibraltar 12 ha (16 % of total area)
- Fairview Village 10 ha (33 % of total area)
- Pinget 10 ha (19 % of total area)
- Loakan Proper 9 ha (4 % of total area)
- Balsigan 8 ha (60 % of total area)
- Asin Road 8 ha (5 % of total area)
- Bakakeng Central 7 ha (3 % of total area)
- Victoria Village 6 ha (50 % of total area)

When comparing most at-barangays risk based on area size, the results fall in favour to larger barangays, and the same 10 large barangays appear in both present and future conditions.



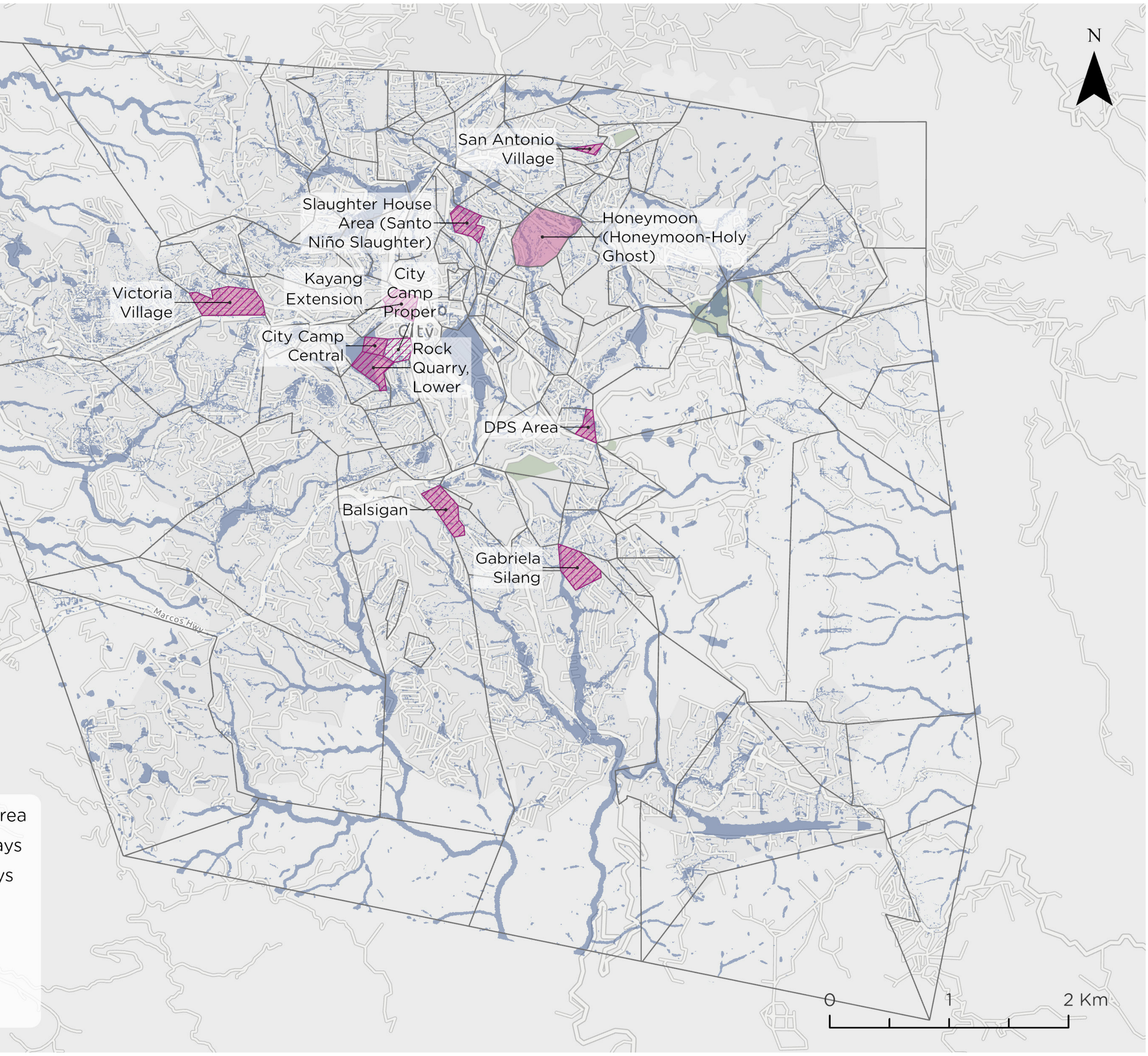


Figure 28: Most at-risk barangays based on percentage area affected. Note that this calculation method favours smaller areas that are densely populated.

6.7 DISCUSSION AND RECOMMENDATIONS

It's worth noting again, that the results of this risk assessment are independent of inundation depth once damage thresholds are crossed. Community surveys conducted in Task Order-05 identify Guisad Central, City Camp Central, Lower Rock Quarry, and Lourdes Subdivision Extension as heavily flood prone areas, which aligns with the large inundation depths modelled in this project (over 5 m in a present 50-yr event in all four barangays). Guisad Central and Lourdes Subdivision Extension, however, were not identified among the top 10 most at-risk barangays, which is partly because the risk model is independent of inundation depths and partly because the vulnerability in these barangays is lower than in other barangays. So, whilst inundation depths and water volumes are certainly important information and must be considered later on in the process when designing adaptation measures, the results of this risk model identify locations based on flood extent and vulnerabilities in order to prioritise plans and next steps.

When selecting areas and/or barangays to progress with in next steps, it's recommended to include the risk maps in the decision process whilst also considering larger planning synergies in the city such as the annual updating of the socio-economic profile, upcoming changes in land use plan and zoning ordinance, planned infrastructure projects, city and barangay budgets, local development investment programming, potential for nature-based solutions, and other aspects that the City of Baguio focus (or wants to focus) on.

Furthermore, note that waterways are also important in the selection process, as the flood extent in a barangay may be alleviated by initiatives in barangays upstream. Flood water does not follow administrative lines and there are often economic benefits to gain when working across administrative boundaries. Results from Task Order-05 "PHI: Gender Transformative Approach for Strengthened Development, Application, and Replication of the Baguio City Smart Flood Early Warning System" described how the culprit of flooding in the barangays City Camp Central and Lourdes Subdivision is believed to stem from blockage of the City Camp Drain Tunnel by debris and garbage during the rains. Hence, extensive flooding is not always solely due to large volumes of water and identifying additional sources for damages in waterways is worthwhile.

Source: Ramboll (picture taken on site by Consultant Team)

7. CONCLUSION AND RECOMMENDATIONS

Figure 29: Nurseries of Mangrove, Philippines
Source: Asian Development Bank

The flood models developed in this report form the basis for the flood risk assessment and Ramboll's overall recommendations in terms of prioritization of areas targeting adaptation investments. These areas will be looked at in more detail during Task 5 of this project, namely the flood mitigation action plan. Furthermore, the models inform a deeper understanding of the existing conditions and distribution of flooding in Baguio, and while the models are uncalibrated, the results have been validated by local stakeholders and historical knowledge confirming that areas identified as particularly exposed to floods are indeed experiencing flooding on a regular basis.

A total of 8 modelling scenarios have been run for each of the four river basin models, yielding a toral of 32 simulations for the assessment in this report. This allowed the assessment of 4 different return periods (3, 10, 20 and 50 years) for both existing climate conditions and future climate projections. The flood mapping results largely confirm the actual recordings on the field, as outlined in the previous Task 1 report (dated January 2021) and as confirmed through local validations with stakeholders in Baguio.

Flood hazard maps show that many houses and roads are exposed to flooding within the Balili catchment, the main drainage catchment in Baguio, flowing downstream north-west. Flooding is seen to occur on roads, alleyways and near buildings. At Barangay level, Barangays with high percentage of flooded area (above 10 cm flood depth) for a 3-year present rainfall event were identified. A closer look at the results yields 10 flood prone Barangays and 2 localized flood prone areas.

Rock Quarry, Lower and City Camp Central located near the City Camp Lagoon are seen to have the greatest percentage of flooded area. Besides the ten flood prone Barangays, flood prone areas are identified at Teachers Camp Compound and near Wright Park. The affected infrastructure within flood prone areas include e.g. roads, buildings, public parks.

The flood risk model, which uses the flood hazard maps together with a vulnerability assessment (taking as point of departure the CDRA work in Baguio), maps current and future risk areas around the city centre, and the northern and eastern parts of the city, as this is more densely populated and therefore have more critical assets, roads, schools, etc.

More than 60 % of the city is at risk of flooding (based on areas covered by low to very high risk). As expected from the flood layers where more areas become exposed in the future, the total area size of areas at-risk increases in the future, albeit not very much, from 61 % to 62 %. As evident in the flood layers, the extent of flooding doesn't increase much in the future and given the risk model is independent of inundation depths, as the exposure to flooding increases only slightly, so does the risk.

While the details of further modelling tasks in the broader context of the project are still to be defined, the hydrodynamic models form the basis for further development and will effectively function as the foundation for further detailing. Key items to be added in the next steps are:

- Including the urban drainage infrastructure in selected catchments and testing conceptual strategies to alleviate flooding issues. The feasibility of undertaking additional surveys in selected sub-catchments will be assessed as part of Stage 5 (Flood Mitigation Action Plan), so as to close drainage data gaps and improve the understanding of the current conditions of the drainage system. These efforts will provide the information required to validate recommended strategies in the flood mitigation action plan and quantify the benefits of such interventions.

- When the 1D models are calibrated and further surveys and measured data is collected, these will be key inputs for the Flood Early Warning System to be developed in Stage 3. The preliminary calibration of such models will be based on results generated by the flood models generated on this task (Stage 2), and further calibration will be completed once sufficient water level/discharge data has been collected from the rivers of interest.

Source: Asian Development Bank

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The ASEAN Australia Smart Cities Trust Fund (AASCTF) assists ASEAN cities in enhancing their planning systems, service delivery, and financial management by developing and testing appropriate digital urban solutions and systems. By working with cities, AASCTF facilitates their transformation to become more livable, resilient, and inclusive, while in the process identifying scalable best and next practices to be replicated across cities in Asia and the Pacific.

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